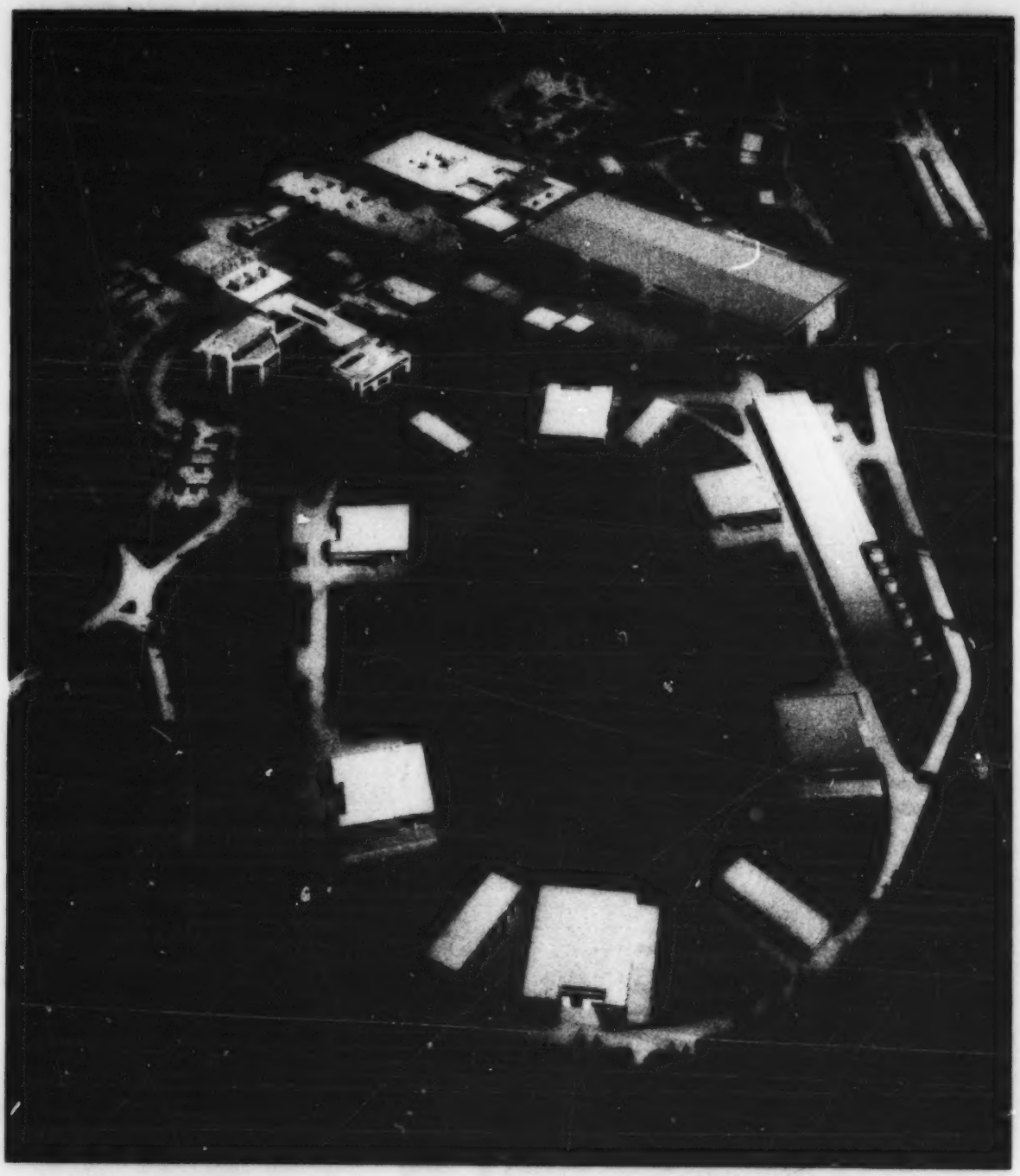


KAON FACTORY

ENGINEERING DESIGN AND IMPACT STUDY

KAON FACTORY
ENGINEERING DESIGN AND IMPACT STUDY

REPORT
OF
THE STEERING COMMITTEE

FEBRUARY, 1990

TRANSMITTAL LETTER

1990-02-28

The Honourable Benoit Bouchard
Minister of Industry, Science and Technology
Government of Canada

The Honourable Stanley Hagen
Minister of Regional and Economic Development
Government of British Columbia

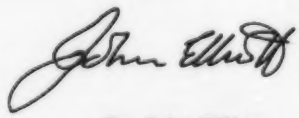
The Honourable Bruce Strachan
Minister of Advanced Education, Training and Technology
Government of British Columbia

The Honourable William Winegard
Minister for Science
Government of Canada

Dear Ministers:

On behalf of the Steering Committee, I am pleased to submit to you the report of the study carried out under the Canada — British Columbia Agreement on the Proposed KAON Factory Engineering Design and Impact Study.

Sincerely,



Dr. John Elliott
Chairman

KAON FACTORY ENGINEERING DESIGN AND IMPACT STUDY

Report of the Steering Committee

HIGHLIGHTS

- The science opportunity for Canada provided by the KAON Factory has been strongly reaffirmed by the world science community. KAON would be a unique, world-class accelerator facility in the major new effort, around the globe, to probe what lies at the heart of matter.
- The refined KAON Factory design has been reviewed by a prestigious, international panel of accelerator experts who unanimously pronounced the project to be technically mature and urged that construction funding be secured with the utmost urgency.
- On the basis of extensive international consultations, it is reasonable to expect that the total foreign participation which can be negotiated could be close to the $200 million target. Substantive responses, far more than expressions of interest, were received. In the absence of a funding commitment from Canada, this constitutes considerable success. The international consultations confirmed the desirability of an early decision on KAON construction.
- The cost, in 1989 dollars, for construction of the KAON Factory is estimated at $693 million over a five year period. The international panel of accelerator experts considers these costs to be on a firm footing. Annual operating costs are estimated to be $98 million (1989 dollars), or $68 million in new funds beyond the current $30 million for TRIUMF.
- A full initial environmental assessment, including two public meetings, found little environmental risk and received considerable positive public comment and approbation. There is no apparent impediment to a construction decision.
- Nearly 200 firms across Canada are capable of being key contractors for high technology components of KAON valued at $316 million (in 1989 dollars). Over 85% of the high technology content of the KAON Factory is of high priority to Canadian industry in such areas as robotics, microelectronics and software.
- The economic impact assessment indicates that during construction, the KAON project would generate up to $550 million of Gross Domestic Product, create up to 17,000 person years of employment and generate up to $1.1 billion of industrial activity. During operations, it is estimated that the project would generate over $77 million per year in industrial activity yielding up to $42 million in GDP and provide up to 1900 person years of employment.

  Despite the fact that a full quantification of all benefits was not possible, the measured project benefits can fully account for nearly 80 per cent of the project costs. The residual would have to be justified on the basis of the economic, social and scientific benefits which could not be quantified.
- The Steering Committee believes that the KAON Factory Project is feasible and can be successfully accomplished within the costs and schedule presented. The Steering Committee is of the unanimous and strong opinion that the Canadian and international scientific community is ready and waiting for an early decision.

92-03481

KAON FACTORY ENGINEERING DESIGN AND IMPACT STUDY

Report of the Steering Committee

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KAON FACTORY ENGINEERING DESIGN AND IMPACT STUDY

Report of the Steering Committee

EXECUTIVE SUMMARY

PURPOSE

This document is the concluding report of the Steering Committee appointed by Ministers for Canada and British Columbia under the terms of the 1988 Canada-British Columbia Agreement on the Proposed KAON Factory Engineering Design and Impact Study. This report summarizes the results and findings of the complete study, full details of which are provided in nine accompanying technical reports.

The study represents the final step in the conventional process of developing a major science initiative for decision by government. Where the initial concept for a KAON Factory was put forward and developed by TRIUMF in 1985 as the initial proposal, the current $11 million study brings together a fully developed proposal and an assessment of its feasibility, costs, support and implications.

BACKGROUND

The proposed KAON Factory would be a major expansion of the current TRIUMF research facility in Vancouver. TRIUMF is Canada's national subatomic research facility and has been serving an active Canadian and international research community since the mid 1970's. TRIUMF first formally proposed the KAON Factory expansion to the Government of Canada in 1985, and the project was reviewed jointly by the NRC and NSERC in 1986. That review found that the probable contributions of a KAON Factory to world science would be extensive and significant, but stated that federal funding should not be at the expense of other areas of scientific and engineering research.

In 1986, the Province of British Columbia, in collaboration with the federal government, commissioned separate studies of the economic impact and industrial spin-off potential of the project. In early 1987, the results of those studies provided the basis for the Provincial Cabinet to give Approval in Principle to the project, and to commit to fund the civil construction component, contingent on overall approval of the complete project by the Government of Canada. The Province has noted that the scale of the project suggests that the federal decision would be made by Cabinet and that funding the project should not have a negative impact on overall science funding levels.

The Government of Canada has maintained that a decision to proceed with a KAON Factory would have a significant impact on the direction which Canadian science takes and that the jointly funded impact study is not a commitment to fund the KAON Factory. It is, rather, a crucial requirement to ensure that the most complete and accurate information is available for a decision on whether to build and operate a KAON Factory.

KAON FACTORY SCIENCE

The science issues to be addressed by the KAON Factory pertain to the basic building blocks and fundamental forces of nature. A recent quantum jump in the understanding of what lies at the heart of matter — a jump to which Canada's TRIUMF has contributed significantly — has led, worldwide, to major new accelerator projects seeking answers to important new questions in this fundamental field. The projects range from the recently-commissioned LEP accelerator occupying a 28 km tunnel in Switzerland, to the nearly-ready HERA project in a 7 km tunnel in Hamburg, Germany, to the just-funded Superconducting Supercollider (SSC) destined to fill an 83 km tunnel in Texas, and to Canada's proposed KAON Factory. Each of these major projects fulfills a role complementary to the others. With its unique intense beams of many different kinds of subatomic particles, Canada's KAON Factory would be strongly positioned to address directly some of the most important new questions in particle physics.

The variety of subatomic particles with which the KAON Factory would carry out its science are generated by first producing an intense beam of high energy (30 GeV) protons and then smashing these protons into a target. The collisions of the protons in the target generate the desired particles. The resulting streams of particles emerging from the target would be collected into secondary beams by magnets. They would include enormous numbers of kaons, antiprotons, other particles and neutrinos: hence the acronym KAON.

The KAON Factory would produce these various particles in numbers unequalled in the world because of the unique intensity of its primary proton beam. It would carry three megawatts of power. In short, this vast production would make the machine a "factory" for such particles: a "KAON Factory".

The technical challenge for the KAON Factory is to produce such a primary proton beam of world-leading intensity. It would do this by using the present TRIUMF cyclotron (0.5 GeV) as an injector of intense proton beams into a new system of accelerator rings intended to boost the energy sixty-fold, to 30 GeV. The existing cyclotron is a proven instrument for this purpose.

The new system of accelerator rings would boost the energy in two steps, first to 3 GeV and then 30 GeV. The acceleration process requires the protons to occur not as a constant stream, but rather as a stream of separated and appropriately packaged bundles. The five successive rings would alternately package and accelerate the bundles. In order: the A-Ring (Accumulator) prepares the injected beam for the B-ring (Booster) which boosts its energy to 3 GeV; the C-ring (Collector) collects the

protons from B for injection in the D-ring (Driver) which drives the protons to full energy; the pulses of intense protons are extended into a continuous stream for experiments by the E-ring (Extender). The manipulation of bundles of protons through a system of rings has been demonstrated at many laboratories around the globe, although the handling of the KAON Factory's intense beams would be a significant technical challenge.

The world scientific community is now waiting for the scientific opportunities to be offered by the various beams of the KAON Factory. Many critical choices need to be made for the initial research program and experimental facilities. In the present study a series of scientific workshops around the globe was organized to discuss the science options and to lay the basis for the critical choices. This workshop series has also strongly reaffirmed the international interest and the excellence of the research opportunities which would be provided by the KAON Factory.

In welcoming Canada's proposed KAON Factory, the international science community provides the impetus for foreign construction contributions to the KAON Factory and also recognizes the place that Canada would have in the world effort in the field. Canadian scientists would participate in the major new facilities abroad which are complementary to the KAON Factory. The opinion has been heard from abroad that Canadian scientists are now subsidized by other countries in their use of international facilities, notably in Europe and the U.S.A., and by operating the KAON Factory Canada would both provide an important part of the international network of large accelerator facilities and also provide some needed balance.

TECHNICAL DESIGN

The current study devoted over 70% of its budget to exacting technical design and testing on a carefully selected subset of the most challenging components of the machine. The purpose of the study was to confirm the feasibility of the design and to refine it sufficiently to develop reliable estimates of the costs of the project. The main results of the technical design are summarized in the following points:

- Performance specifications for the TRIUMF cyclotron as an injector for KAON were determined.
- Working prototypes were developed and tested for each of the principal devices needed by KAON: 1) to extract the beam from the TRIUMF cyclotron; 2) to chop the constant TRIUMF beam into batches for the five-stage KAON machine; 3) to carry the beam in high vacuum over four kilometers; 4) to kick the primary beam from ring to ring at each stage in the machine; 5) to produce the acceleration with an electric field; 6) to bend the path of the beam to the correct arcs; and, 7) to act as the primary target for production of secondary beams.
- The shape of the main rings was optimized to a race-track shape, with long straight sections to provide much cleaner transfer of the beam from ring to ring and especially for final extraction. To fit the new shape to the local geography, a new reference design was developed with the main rings located to the west of the present TRIUMF site.
- An alternative design was investigated for the high voltage devices used to accelerate the beam in the Booster Ring. Full prototypes for two designs were built, and the performance of the newer "Los Alamos" design promises to be superior.
- A complete prototype of a Booster bending magnet has been designed and fabricated. This work confirmed both this specific magnet design and the design techniques which would then be applied to all subsequent magnets.
- A full prototype power system for the magnets was configured and tested to develop and demonstrate its feasibility in meeting the specialized requirements for frequency, current and switching time.
- Detailed specifications were developed for: 1) the performance and architecture of the computerized machine control system; 2) the robotic and remote handling requirements of the machine and facility; 3) the safety and occupational health protection of staff, visitors and the general public.
- A complete conceptual design and guidelines for the site layout were developed. Facilities and service designs were prepared for all civil engineering aspects of the project including fourteen specific buildings, a series of tunnels and underground complexes and all site services.

The design and testing work has demonstrated the technical feasibility of the project and provided three levels of precision for cost estimates. The overall configuration of the machine and the related civil design has been well established, therefore, a 10% contingency is used for the conventional construction estimates. The requirements and designs for magnets and their power supplies have been examined in great detail as a primary topic of this design study, therefore, a 15% contingency has been applied to their cost estimates. Finally, a somewhat larger contingency of 20% has been applied to the other technical components of the project to accommodate both future adjustment of design and variation in industry quotations.

EVALUATION of the ACCELERATOR DESIGN

The technical design work for this study was carried out through TRIUMF, with extensive use of outside experts and consultants. Late in the study, the principal features of the revised design were subjected to review by an outside panel of prestigious international experts. This eight-member panel was established by the Steering Committee and was made up of people with broad experience in building and operating large accelerator facilities of the magnitude of the KAON Factory from Japan, Switzerland, United Kingdom, Germany and the United States.

The panel advised the Steering Committee that: "The TRIUMF-KAON Project will provide a unique world class facility for basic research in particle and nuclear physics with performance capabilities which will not be available anywhere else. The committee unanimously agrees that the project is technically mature and urges that funding be secured to pursue the construction with the utmost urgency. The cost of major subsystems of the KAON Project has been evaluated in depth. The estimates are in many cases based on quotations or budgetary estimates by industry, and experiences of other laboratories. We consider the cost estimates as presented in the Project Definition Study to be on a firm footing. The allowed contingencies of 10% for conventional construction and 15-20% for technical components are sufficient."

INTERNATIONAL SUPPORT

The Steering Committee established a delegation to consult internationally and determine the extent of foreign governments' interest in participating in KAON. These consultations were arranged by External Affairs and International Trade Canada. Foreign participation is essential for KAON to proceed. Of the 800 scientists expected to work at KAON during a given year, two thirds would come from abroad, and one-third would be from Canada. TRIUMF/KAON staff had estimated that foreign participation in components valued at $200 million was a reasonable target. Based on the number of foreign scientists expected to be working at KAON, it was proposed that about one-half of foreign contributions ($100M) would be appropriate from the United States; the balance would be split equally between Europe and Japan.

The proposed mode of participation, contributions in the form of components manufactured by the participating countries, was successfully used by West German scientists for their HERA accelerator at Hamburg. This mode is appropriate where the facility has unique characteristics attracting wide international interest, and where scientists from the host country would be in the minority. KAON falls into this category. The delegation consulted with government officials, or their designates, in seven countries: France, Italy, Japan, Korea, United Kingdom, United States and West Germany; preliminary discussions were held with the European Community.

Given that Canada had not made a commitment to KAON, the delegation might only have obtained expressions of general interest from foreign partners. The physics communities in several of the countries consulted, however, had shown strong support for KAON and had expressed this support to their own funding agencies. As a consequence, a number of countries provided substantive responses, far more than expressions of interest. It must be emphasized, however, that all the responses express intentions; commitments can only be obtained after Canada has committed to KAON. Extensive negotiation will be needed to transform intentions into commitments.

Written responses to these proposals have been obtained from all countries consulted, with the exception of Japan. Japanese officials are unable to provide a written response in advance of a commitment to the KAON Factory by Canada, but have indicated they would provide every possible assistance to the KAON Project, within the constraints of the Japanese decision-making process.

The responses from Germany and the United States, two key participants, are as positive and substantive as could be expected in the context of these consultations. The U.S. Department of Energy has indicated its intention to request in its budget submission funding for KAON at $100M (Cdn) over five years. German laboratories would participate in KAON at a level which at least matches Canada's earlier contribution to the HERA accelerator. With these two key responses and the other expressions of intent, there are reasonable expectations that the total participation which can be negotiated could be close to the $200M target. This outcome, a success in the context of these consultations, is a consequence of the interest and support for KAON science by the subatomic science communities in other countries.

CANADIAN INDUSTRIAL CAPABILITY

The KAON Factory would require many components involving an array of industrially important technologies. This study examined the current and potential capability of Canadian industry to provide the advanced technology components, and assessed the overall industrial importance to Canada of the technologies involved. The work was carried out in collaboration with other provinces and federal agencies. In summary:

- Over 80% of the high technology components of the KAON Factory can be supplied from within Canada. Nearly 200 firms across the country were identified as possible prime contractors or key subcontractors.
- Firms capable of being key contractors were identified in seven provinces, from British Columbia through to New Brunswick. The largest numbers of capable firms were identified in Ontario, British Columbia, and Quebec.
- Of the high technology content, over 85% is in areas of high industrial priority to Canada such as control instrumentation, software, high power magnets, robotics and microelectronics.
- An initial estimate of the regional distribution of contracts was made based on the distribution of firms, with over 85% of potential contract values in three provinces: over $110 million for Ontario, about $100 million for British Columbia and over $60 million to Quebec.

The strategic impact of the project on Canadian industry can be maximized through careful attention to the structure and size of specific contracts.

Parallel to the international consultation process, a separate multi-lateral meeting was organized for designated technical representatives from all potential participant nations to receive a technical updating on the design and to discuss the possible

components or expertise which they would consider offering to the project. A tentative listing of possible contributions was developed, but with the clear understanding that it does not yet represent any specific commitment on either side. Canadian industrial development could be affected by international contributions of high technology components. Negotiations to determine specific contributions must make careful selections among offers of priority technology components from foreign contributors. Contributions must be judged in the context of Canadian industrial development priorities and the possible development of desirable linkages between Canadian and foreign design and fabrication facilities.

COST ESTIMATES

A major objective of the study was to provide an accurate assessment of the costs of constructing and operating the KAON Factory. The proposed construction period of five years was confirmed and provides the basis for the construction cost estimate.

In summary, the revised cost estimates for the KAON project, in 1989 dollars are:

- Five year capital cost of construction is $693 million, including:
  - — cost of technical components ($405 million)
  - — cost of conventional facilities ($203 million)
  - — cost of design, management and installation ($85 million)
- Annual operating costs are estimated to be $98 million after construction including:
  - — baseline costs of TRIUMF ($30 million)
  - — new costs for KAON operations ($60 million)
  - — support for Canadian university researchers ($8 million)
- Annual operating costs during the construction period would increase from current TRIUMF levels toward those needed for full KAON operation. The total new requirement is estimated to be $85 million over the five year period, primarily in the fourth and fifth years.

The cost of capital construction includes contingencies which range from 10% to 20%, depending on the status of technical design.

The cost of providing the site for KAON is not included in the capital program cost estimate since it is assumed to be a provincial responsibility and not to affect the total cost substantially.

Detailed tables for the capital cost estimate, annual cash flow requirements for construction and annual operating costs are included in Chapter 8.

OTHER ISSUES

The study examined three sets of possible issues associated with the project as a major item for government decision, including the legal, environmental and economic implications of the project:

Legal

The legal implications of the project would be relatively few. Specific issues considered included real property, environmental issues and the corporate/legal structure for the KAON Factory organization. The assessment concluded that, on the basis of the information available at the time of the examination, there does not appear to be any legal issue which would preclude the project from proceeding. Specific proposals and options for dealing with the issues in these areas would need to be addressed from a legal perspective as further information becomes available.

Environmental

The environmental impact of the KAON Factory would be relatively minor. A broad initial assessment was carried out, including two public meetings. The public response concerning the conduct of the consultation process was very positive and both the process and KAON received a general approbation at the second meeting. Few specific issues were found to require measures to mitigate their effects. Most of the potential impacts are of minor consequence and involve little or no measurable environmental risk. Overall, the effects are considered manageable and more detailed study does not appear to be required prior to a decision on project approval.

Economic

The potential benefits of a research facility such as the proposed KAON Factory could be considerable. These benefits would arise both from the initial construction phase and from the research which would be performed at the completed facility. During construction, the impact assessment indicates that the KAON project would generate up to $550 million of Gross Domestic Product, create up to 17,000 person years of employment and generate up to $1.1 billion of industrial activity. During operations, it is estimated that the project would generate over $77 million per year in industrial activity yielding up to $42 million in GDP and provide up to 1900 person years of employment. The studies have provided a useful framework for categorizing the costs and benefits of the KAON project. Costs proved more easy to quantify than benefits and, as such, the project is a difficult challenge for economic assessment. Despite the fact that a full quantification of all benefits was not possible, the measured project benefits can fully account for nearly 80 per cent of the project costs. The residual would have to be justified on the basis of the economic, social and scientific benefits which could not be quantified.

CONCLUSION

The Steering Committee believes that the KAON Factory Project is feasible and can be successfully accomplished with the costs and schedule presented. There is a reasonable expectation that $200 million in international funding can be negotiated. International support for the science and the proposed experimental program is excellent. The Steering Committee is convinced that all the information needed to make the decision is available in this report and its accompanying technical reports. The Steering Committee is of the unanimous and strong opinion that the Canadian and international scientific community is ready and waiting for the KAON Factory to proceed. An early decision is clearly needed.

Chapter 1

INTRODUCTION

THE NEW AGE IN PARTICLE PHYSICS

The KAON Factory proposed by TRIUMF would be a unique, world-class, large accelerator facility intended to explore very fundamental questions in science about the world in which we live. In the past decade there has been a great leap forward in our knowledge of what lies at the heart of matter: of the basic building blocks of nature and the fundamental forces. We now know that the neutrons and protons in the nucleus of the atom are made of quarks — which come in six different varieties (Table 1-1) — and that the forces which operate deep inside the atom are closely related to electromagnetism.

Up Down	Charm Strange	Top Bottom

Table 1-1 The Six Varieties of Quarks

TRIUMF contributed significantly to this breakthrough in our knowledge. The new age in particle physics was heralded, in 1983, by the discovery in Geneva, Switzerland, of three new particles (called W^+, W^-, Z^0) which are related to the particles of light which are so important in our everyday world. In the same year, experiments at TRIUMF found the most important property of these new partners of light, their handedness. These new partners of light are the agents of radioactivity and, in our world, the interactions of radioactivity are left-handed: pointing the thumb in their direction of travel they turn around their axis like the fingers of the left-hand, not the right.

New questions arise from new knowledge. The KAON Factory, or simply KAON, would join a small network of perhaps half a dozen very large new accelerator facilities which, worldwide, are intended to address the scientific challenges emerging from our recent knowledge of quarks, leptons and unified forces. The most recent of these is a new accelerator, built jointly by the European countries in Geneva, which is called LEP (several times KAON in cost). LEP is a ring of magnets in a tunnel 28 km in circumference. It is intended to explore the detailed properties of Z^0. Since its work began, only a few months ago, LEP has already shown that nature provides only three pairs, or families, of quarks and, equally three pairs of leptons which are the electrons and its relatives. Germany is building its own home-base accelerator, HERA (roughly equal in cost to KAON) to explore the interactions of electron beams with the three quarks inside the proton. The HERA accelerator is located in a 7 km tunnel under the city of Hamburg. The largest of the new accelerator projects is the Superconducting Super Collider (SSC, more than ten times the cost of KAON and whose construction funding was recently approved by the U.S. Congress). The SSC will be located in an 83 km tunnel south of Dallas. It is intended to find new particles responsible for giving the different quarks different mass. Because of this mass difference, we and the world in which we live are made of the first family of quarks: the "up" and "down" quarks.

THE KAON FACTORY COMPLEMENTS OTHER WORLD FACILITIES

The KAON Factory would be a unique and important complement to these new facilities. Although our ordinary world is dominated by the first quark family, the second quark family — containing the "strange" and "charmed" quarks — is now on centre stage for the new physics. The lightest carrier in nature of the strange quark is an ephemeral particle called the kaon whose lifetime is measured in billionths of a second. It can be created and studied in the laboratory. KAON would be the world's only intense source of kaons (and many other short-lived particles) for future experiments on the second family of basic building blocks.

Kaons would be produced at KAON by having very intense high-energy proton beams bombard appropriate targets. At present, TRIUMF uses a special accelerator — the world's largest cyclotron — to produce a very intense proton beam of sufficient energy to create a light relative of the kaon: the pion. It is composed of members of the first quark family. In order to create the heavier kaon the energy of the present TRIUMF proton beam needs to be increased sixty-fold. The present TRIUMF cyclotron would, for KAON, be used as an injector into a system of accelerator rings which would achieve the required energy boost in two stages. The rings are described below. The largest of them would be located in a 1 km tunnel adjacent to the present TRIUMF site.

KAON would place Canada on the world map in this field of science through high intensity, not high energy. The complementary projects abroad have a hundred-fold or more greater energy (and longer tunnels). By having proton beams of a hundred-fold or more greater intensity than its high-energy competitors, KAON would outdo them by the same factor in the production of kaons and many other particles. It is these unique secondary beams which will bring the world to KAON.

INTERNATIONALIZATION OF THE KAON FACTORY

Since the initial KAON proposal in late 1985, the development within Canada toward a decision about KAON has occurred in a number of steps culminating in the results of the present study. When the proposal was first submitted to the Federal Government by TRIUMF, a two-step review for Canadian funding was established jointly by the National Research Council of Canada (NRC) and the Natural Sciences and Engineering Research Council (NSERC).

In the first step of the NRC/NSERC review, a Technical Panel composed of very prestigious international technical experts examined KAON's science and the proposed accelerator system. The report of the Technical Panel had recommendations with the following essence:

> "There is a very strong scientific case for building a KAON Factory."
>
> "The first country to decide to build one would contribute an outstanding international facility of great scientific value. Canada has a unique opportunity to play that role with a project which, though expensive, is within its resources."
>
> "The machine as proposed is technically feasible and capable of achieving its design goals."

In the second step, a KAON Factory Review Committee composed of Canadian leaders from many scientific disciplines considered the potential impact of KAON on Canada's science. With the report of the Technical Panel as input it reaffirmed the scientific merit and technical merit of KAON and focussed instead on conditions, especially financial, which need to be met to justify approval. These conditions included:

> "Contribution from outside Canada of at least $75M" (which is about 1/8 of KAON's construction costs), and "Federal contributions to the KAON Factory should not be at the expense of other areas of scientific and engineering research."

The KAON Factory Review Committee focussed on the latter condition and concluded:

> "Unless the current level of support for basic scientific research in Canada is significantly increased, projects of the magnitude of the KAON Factory cannot proceed without major and widespread disruption of excellent ongoing research. The Review Committee believes that in the present case such disruptions would not be justified, and therefore cannot recommend that the Councils support the KAON Factory at the present time."

The two Councils, in transmitting the Review Committee's report to the federal government in early 1987, endorsed its conclusions.

The KAON Factory is big science. Even its strongest proponents supported the view that KAON could not proceed without new funds. The advocates of KAON, in continuing to seek funding for it after the report of the Review Committee, sought to fulfill the preconditions established by that committee.

The development of the idea for KAON has been led by TRIUMF and Canada. Canada has achieved its present place in subatomic science through the excellence of TRIUMF. KAON would be a natural future development of TRIUMF's science and it would use TRIUMF's present accelerator as an important first piece of the KAON system. Thus it is not surprising that Canada was the first in the field to study the potential of a KAON Factory, culminating in a formal proposal in 1985.

Other nations rapidly followed Canada's lead, producing competing proposals for a KAON Factory. Such proposals were prepared by scientists and laboratories in the United States as well as in Europe and in Japan. Clearly the time for KAON had come and there was a worldwide interest. Formal evaluations of those various proposals highlighted the great interest in the science of KAON. Uniformly, the very high science priority of KAON was reaffirmed and a consensus attained that one KAON Factory should be built to serve the world. In 1987-89 the various nations pursuing the science of KAON deferred to Canada's lead and decided to join Canada's KAON rather than build a competing facility. Thus KAON was transformed from a proposal for a major national facility for Canada into a world facility operated by and in Canada.

The federal funding necessary for KAON construction was, in the event, cut in half by subsequent developments.

The B.C. Government became a strong proponent of KAON in early 1987. It gave a contingent commitment to fund the civil costs of KAON — the buildings and tunnels which constituted about a sixth of the total construction costs package. Further, it pushed the vision that Canada's KAON could be transformed from a national facility into a world facility with, perhaps, a third of the construction costs being provided from abroad. In this vision, the federal portion of construction costs would be roughly cut in half, rather than Ottawa providing all the funds as in the initial proposal.

In furthering the internationalization of KAON, British Columbia and Canada agreed to carry out a joint Federal-provincial exploration of potential foreign support for KAON construction. The Canadian delegation abroad, led by Dr. Geoffrey Hanna, reported in early 1988 that there was considerable foreign interest. It was this exploration which also led to the elimination of foreign competition for KAON. Simultaneously, several economic impact studies for KAON elucidated the potential economic benefits of KAON to Canada.

With their raised interest in Canada's KAON, Canada's six Economic Summit (G7) partners, whose senior particle physics representatives met in Vancouver in May, 1988, strongly urged Canada to fund KAON, to proceed with a project definition study and to seek their construction support. A minute from that meeting is as follows:

> "Canada reported on progress since last year on

its proposal to build a KAON Factory at TRIUMF. International collaboration on construction funding has been explored with encouraging results, and a decision by Ottawa appears near on the final project definition studies ($11M) including negotiation with foreign partners. The Working Group reaffirmed last year's conclusion that there is a very good scientific case for a machine of this type for the sound development of high-energy physics. It also concluded that an early decision by Canada to proceed with its KAON Factory would be very welcome and it encouraged Canada to seek interest and scientific engagement from the international community. It was noted that other projects, such as the Japanese Hadron Facility, would explore interesting fields complementary to the KAON Factory."

These developments then set the stage for the present study in which Canada and British Columbia jointly agreed to seek the information which was needed by Canada to make a firm decision about KAON construction funding. Each government agreed to provide half of the eleven million dollars for this study.

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Chapter 2

INTRODUCING THE KAON FACTORY

RST LOOK AT THE KAON FACTORY

rrounded by a west coast green belt, the KAON Factory vould occupy a 33 hectare complex near Vancouver on outh campus of the University of British Columbia, also ded by Pacific Spirit Park and the Discovery Research KAON would be a unique world class research facility andsome Canadian coastal setting. It would link Canada future through international scientific excellence.

gure 2-1 shows the complex looking from above the main From this perspective, the site is almost a kilometer with three major features: a large oval, a three storey gon, and three long buildings.

e industrial building (marked "A") is where the particles their trip through the main machine. This source has operating as a stand alone research facility for fifteen ; now to be used as an injector, this facility is known nd the world as TRIUMF.

e distinctive octagonal building (marked "B") stands three stories high. The octagonal building is as much below ground as above, and it is the center of another, smaller tunnel which itself houses a major stage of the machine. One can see an overhead skywalk connecting the structure to a lower, office style building that arcs around the back of the octagon, and is linked to a third structure, also offices.

The open oval area in the foreground is about the length of four football fields. This large oval is almost a signature for the KAON Factory. Around its perimeter, a series of low buildings, linked by a service road, suggest that there is much more beneath the surface. The big oval actually covers a one kilometer long race-track shaped tunnel in which the main part of the machine is built.

Three long industrial style buildings sweep across the rear of the site, and together span almost six hundred meters. From the left, the two largest buildings are offset at an angle to the view, while on the right, the third seems to grow out of the far side of the oval itself.

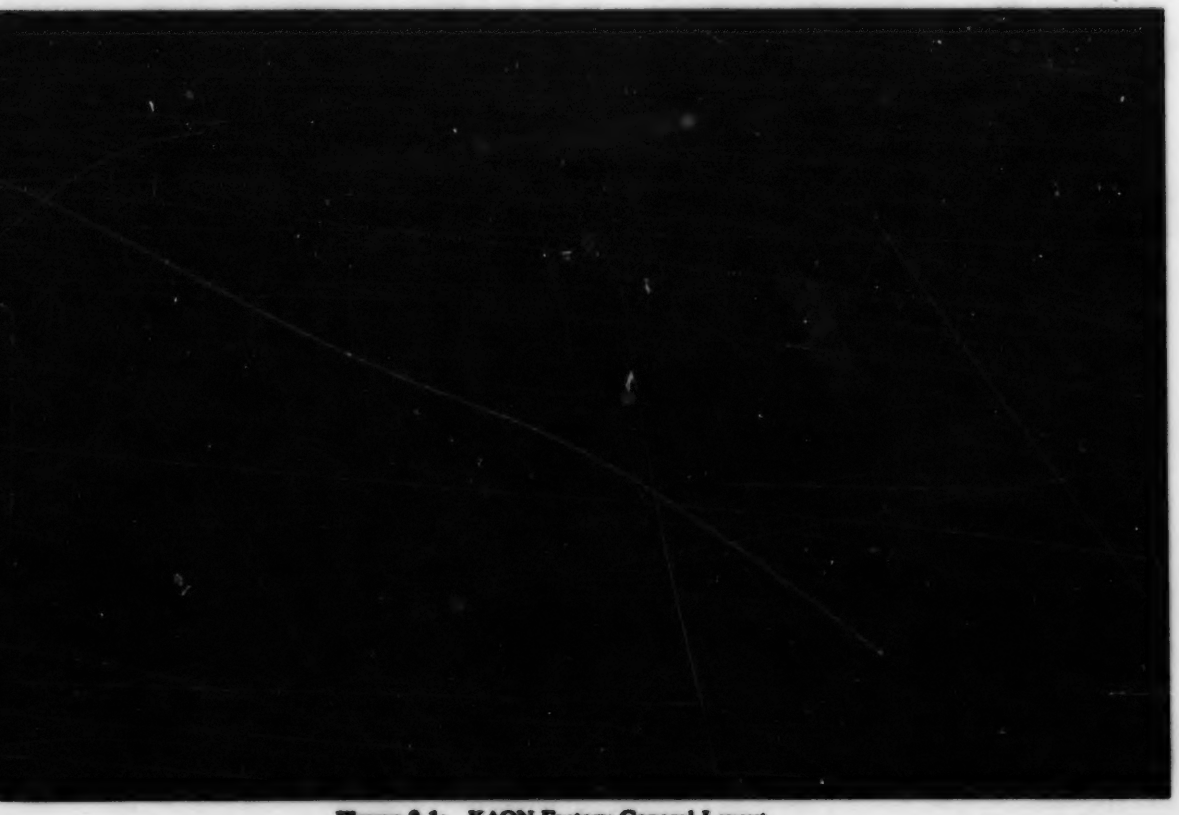

Figure 2-1: KAON Factory General Layout

The oval, the octagon and these long buildings only hint that the site is home to a very special research machine. The middle and longest building is well serviced with walkways and roads, making it clearly a focus of attention for many people. In fact, for the scientist who comes to use the KAON Factory, this is the heart of the facility for this is the main experimental hall.

HOW THE KAON FACTORY WORKS

The KAON Factory is a particle accelerator. In fact, the particles it accelerates are protons, the nuclei of the lightest atom, hydrogen. Some machines accelerate heavier particles, others accelerate lighter ones, notably electrons. Of course, the most ubiquitous electron accelerator in the world is the television picture tube.

Like all particle accelerators, the purpose of the KAON Factory is to provide high speed beams for experimenters to produce "pictures" of what lies at the heart of matter; of the basic building blocks and fundamental forces of nature.

The basic concept for all such machines derives from the basic property of charged particles: they accelerate when in an electric field. One other factor makes them manageable: the path of a charged particle will bend into an arc when it crosses a magnetic field.

In a television set, the electrons are accelerated towards the screen with a high voltage. A series of magnetic coils are controlled such that electrons hit the right spot at the right time. A fluorescent effect makes spots of light, and the viewer's mind puts the dots together into a visual image.

In spite of their variety of shapes and sizes all particle accelerators have the same basic components:

- an evacuated chamber to carry the beam of electrically charged particles, normally protons or electrons;
- high-voltage generators, usually working at radio frequencies, to provide the electric fields to accelerate the particles;
- magnets to steer the particles in a closed path for many passages through the same accelerating device, and to focus or contain them within a narrow-diameter beam;
- electric power supplies to drive the various systems;
- cooling systems to limit electrical heating of components;
- diagnostic and control systems for both the beam and hardware.

At KAON, the TRIUMF source would create a stream of protons and accelerate it with a voltage much higher than in any television set, but not high enough for the new research purposes now sought. Unlike a television, which has a straight shot from front to back, TRIUMF bends the beam around in a spiral many thousands of times, so the beam travels faster and faster through higher and higher voltages. As its speed and energy goes up, the beam is harder to bend, and its curving path takes a larger radius. The TRIUMF machine is over sixteen meters in diameter, so the radius of the curve for its fastest protons is over eight meters. One more point, all this must be done in a vacuum, so that practically no other particles can get in the way of the speeding beam.

The first stage of acceleration would be provided by the existing TRIUMF 500 MeV cyclotron. This is one of only four accelerators in the world capable of providing beams of the required 100 microamperes intensity (6×10^{14} protons per second) in this energy range.

In the KAON Factory, the beam emerging from the TRIUMF cyclotron would have its energy boosted by a factor of sixty. In speed terms, this puts the particle far inside the realm of relativity; TRIUMF produces protons at 75% of the speed of light, KAON would produce protons at 99.95% of the speed of light. While speed is a practical concept in our everyday experience, it is replaced by measures of energy, (in electron volts) when working close to the speed of light. In these terms, TRIUMF is a 500 million electron volt (500 MeV) machine; while KAON would be a 30 billion (or Giga-) electron volt (30 GeV) machine.

FOUR KILOMETERS OF VACUUM PIPE

At the energy levels of KAON, it is not possible to bend the beam in arcs tight enough to fit inside a single vacuum chamber, as TRIUMF does. Instead, the beam would travel inside a special vacuum pipe, with built-in electric devices along the way to accelerate it. The pipeline forms a ring enabling the beam to cycle through it thousands of times until the desired energy is achieved.

To raise such an intense beam to higher energies, it is necessary to use synchrotron accelerators in conjunction with storage rings. Because the protons become harder to bend at higher energy these machines have large circumferences, over 1 kilometer at 30 GeV, and are therefore installed in tunnels underground. They consist essentially of strings of electromagnets and radio frequency accelerating cavities, through which is threaded a rectangular vacuum pipe for the beam, typically 15 cm x 10 cm in cross-section. Each accelerator is followed by a storage ring which prepares the beam for the next stage. This separation of acceleration from storage allows more pulses of beam to be passed through the system per second, maximizing the intensity. Five new rings will be required:

- the Accumulator ring and Booster synchrotron, located in the Booster tunnel, 216 meters in circumference, and cycling 50 times per second.
- the Collector ring, the Driver synchrotron and the Extender ring, located in the 5-times-longer main tunnel, and cycling 10 times per second.

THE BOOSTER COMPLEX

Raising the beam energy by a factor of sixty cannot be economically achieved in a single step, so the energy of the injected beam from TRIUMF would first be boosted by a factor of six in a Booster ring. The Booster ring is housed in the tunnel around the octagonal building, known as the Booster complex.

Accumulator Ring. This ring would gradually accumulate the regular stream of beam bunches produced by the cyclotron at intervals of 43 billionths of a second (nanoseconds) into 40 notional "buckets" around the circumference. The process is similar to filling a moving circular train of boxcars from regularly spaced piles on a conveyor belt. It continues over 1/50 second, time enough for about 20,000 orbits of the ring. Finally, the 40 bunches are transferred from the Accumulator to the Booster, which has the same circumference.

Booster Synchrotron. In the next 1/100 second this synchrotron would accelerate the beam bunches from 74% to 97% the speed of light, increasing their energy to 3 GeV. The use of a booster stage reduces the cost of the whole system. Because the beam shrinks in diameter during acceleration it enables the magnets in the much longer 30 GeV synchrotron to be significantly reduced in size and cost. To achieve the increase to 97% the speed of light, the radio-frequency system must sweep through a large frequency range. The booster system reduces the complexity and cost of the overall KAON radio-frequency accelerating system by providing almost all the frequency rise in a small ring where only a low energy gain is required.

Figure 2-2 shows the Booster complex with a cut-away view of the tunnels and below-ground structures. The octagonal building houses the control room for the total complex, and is filled with equipment to power and support the Booster stage which encircles it.

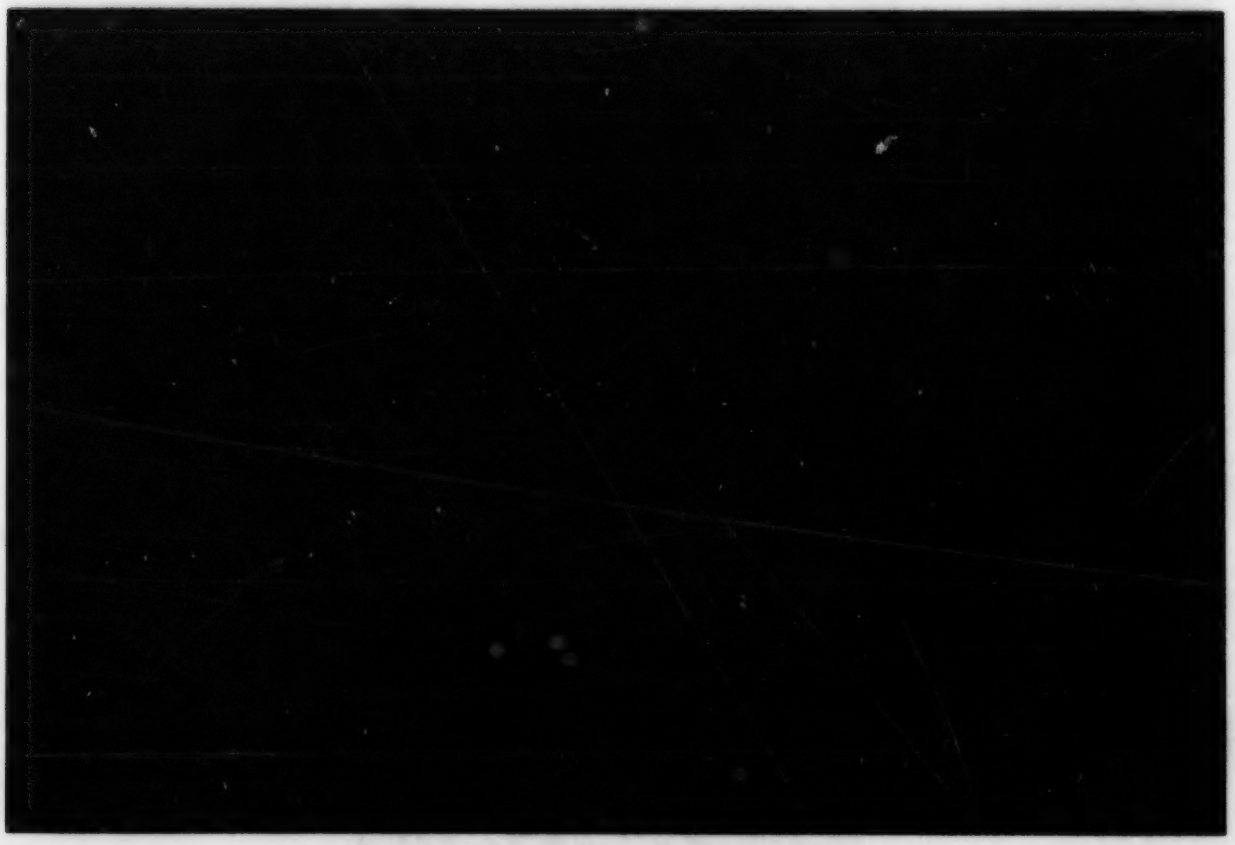

Figure 2-2: Cutaway View of the Booster Complex

THE MAIN TUNNEL

The second increase in beam energy would take place in the main tunnel complex of the facility which includes three rings: the Collector, the Driver and the Extender. These rings are five times as long as the Booster, and are housed in the one kilometer racetrack shaped tunnel under the main oval.

Figure 2-3 shows a cut-away view of the main oval with the tunnel and one of the six low service buildi Again, the building extends farther below ground than al and is full of equipment to power the hundreds of parts o machine that are housed in the main tunnel.

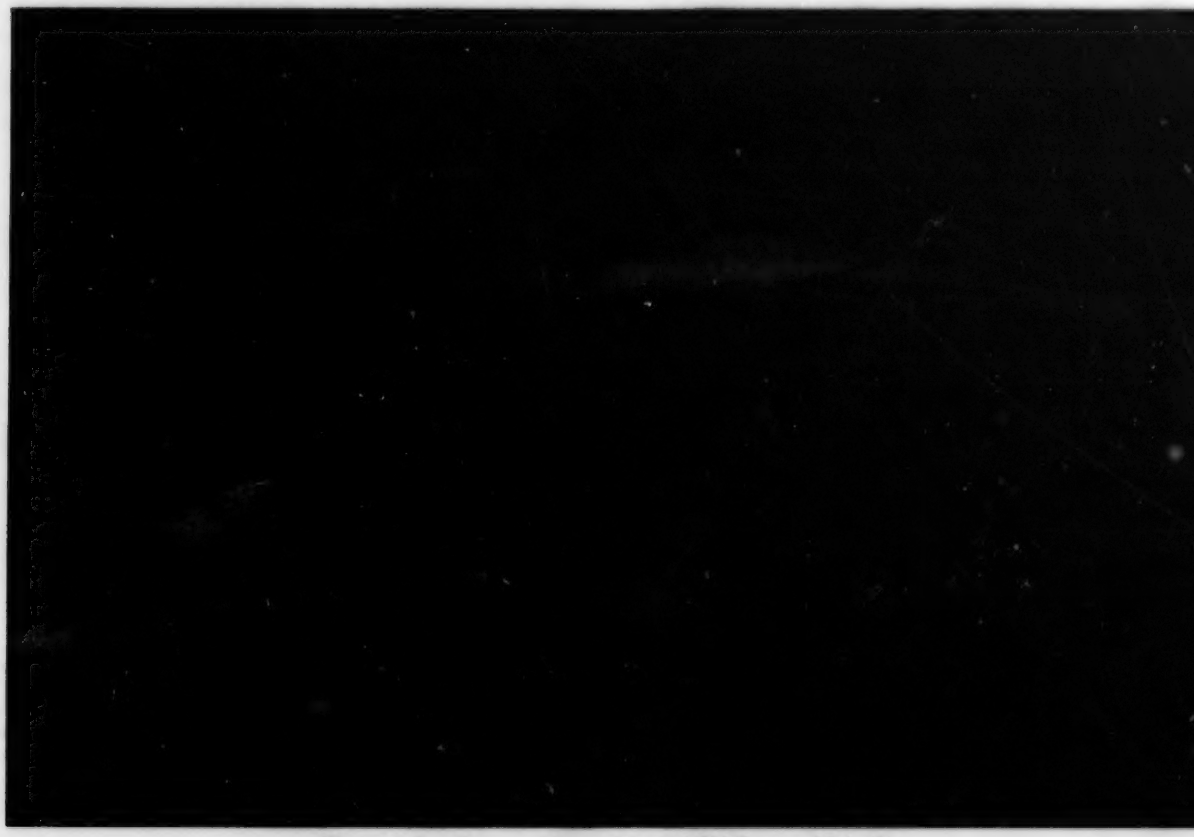

Figure 2-3: Cutaway View of the KAON Factory Main Ring

Collector Ring. This fixed-energy ring, located in the main tunnel, would be 5 times longer than the Booster and would be used to collect five successive bunch trains from it end to end over a period of 1/10 second. Special radio-frequency cavities are used to lengthen the bunches and avoid the microwave instabilities which would otherwise be expected at full intensity.

Driver Synchrotron. This would be located immediately beneath the Collector and would be used to accelerate the 200-bunch train assembled there by a factor of ten from 3 GeV to 30 GeV. The speed of the protons would increase from 97% to 99.95% of the speed of light and they would become 8 times more massive. The frequency of the accelerating voltage must only increase by 3%. The bunch train extracted from the Driver is about 3 millionths of a second long and can be used directly for neutrino experiments. Neutrinos are so weakly interacting that it is beneficial to use them in sharp pulses in order to better distinguish real signals from cosmic ray background.

Extender Ring. For experiments with strongly interacting particles, however, like kaons, pions and antiprotons, a sharp pulse would produce too many simultaneous interactions, indistinguishable from one another. For these the beam is transferred to the Extender. This is a deliberately imperfect storage ring from which the protons are gradually extracted into the main experimental hall over the full 1/10 second cycle time.

A FIVE-RING MACHINE

To summarize, while two rings are used to raise the energy in the Booster and Driver, the overall KAON Factory design uses a total of five rings in a series, with three used either to prepare the beam for subsequent acceleration or, at the end, for extraction.

Connecting the rings together into a complete machine pipeline, there are transfer lines from TRIUMF to the first ring, and from each ring to the next in the series. To move the beam into a given transfer line at the right time, a magnetic device called a kicker acts like a switch to redirect the beam path. To get in and out of the five rings, the KAON Factory has a total of six transfer lines. The pipeline complex of rings and transfer lines makes up a vacuum vessel nearly four kilometers long. The complete series of rings is shown schematically in Figure 2-4.

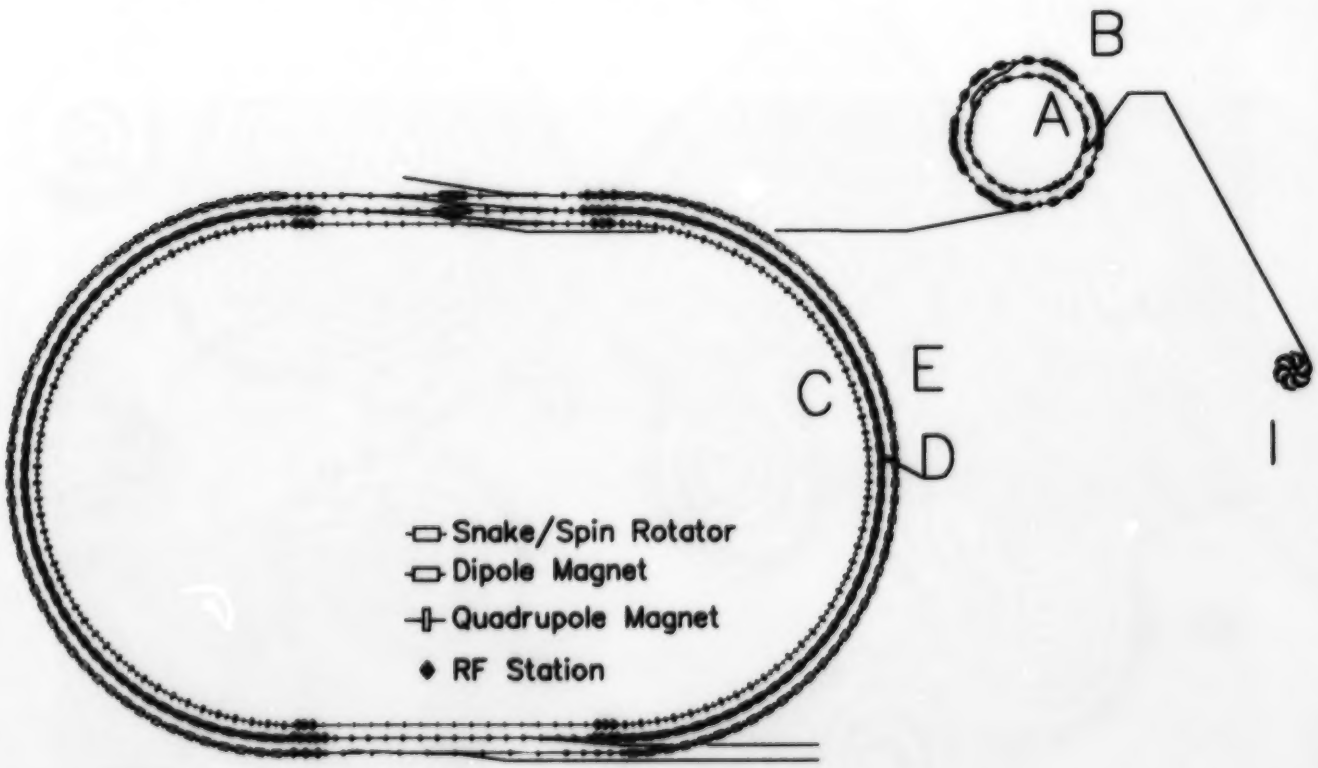

Figure 2-4: Five Rings of the KAON Factory
I - Injector Cyclotron; A - Accumulator; B - Booster;
C - Collector; D - Driver; E - Extender

EXPERIMENTAL HALL

While KAON would be a proton accelerator, most of the researchers coming to use its beams will not be interested in the protons directly from the machine. Rather, the world research community is keenly interested in the wide range of other sub-atomic particles which can be produced by smashing the proton beam into a specialized target of copper or tungsten, for example. The vast numbers of collisions between beam protons and target atoms produce combinations of the parts of protons, parts known as quarks.

The world as we know it in everyday experience is made up of matter composed of up and down quarks. These two are only the first pair, or family of quarks. There are two other families containing quarks called: strange, charm, beauty, and top. In addition, nature provides the opposites (or "antis") of the basic quarks. Antimatter is made of antiquarks.

The strange quark is of particular interest to researchers. Part of its mystery, for example, comes from the peculiar behavior of the strange quark as time is reversed. Unlike our everyday up and down quarks its history changes when time is run backward. The most easily produced carrier of the strange quark is the "kaon," first observed in cosmic rays in 1947, currently produced in small numbers in several laboratories and now proposed to be produced in quantity at the KAON Factory.

Kaons are only one product from KAON Factory targets. Streams of pions, anti-protons and neutrinos also come from the impacts of protons on these production targets. Together these resultant streams of particles can be collected by magnets and organized into useable secondary beams. Researchers put their experimental equipment at the end of one or another secondary beam to conduct their work.

Figure 2-5 shows the main experimental hall with four main lines for secondary beams and some examples of the equipment which experimenters would bring to the KAON Factory. Each beam line can supply a different type of subatomic particle, over a range of energy.

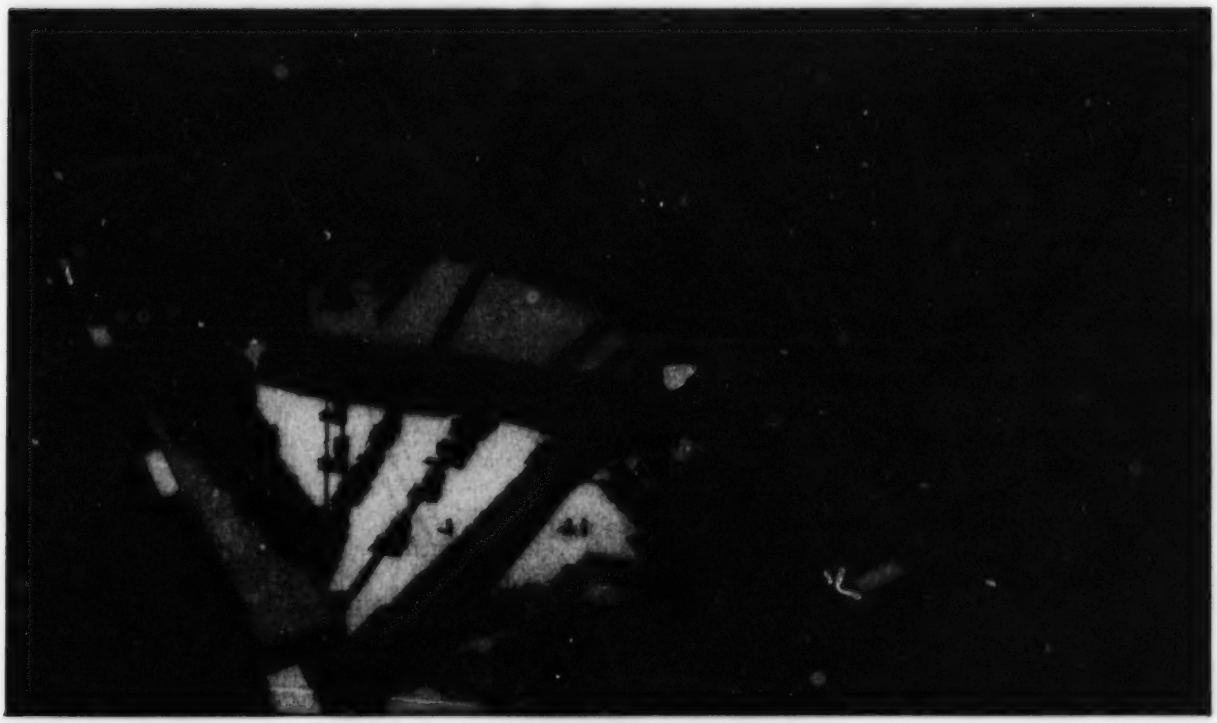

Figure 2-5: KAON Factory Experimental Hall

Chapter 3

DESIGN STUDY RESULTS

PURPOSE

The main purpose of the technical design and prototyping component of the study was to develop a high degree of confidence in the technical specifications of the machine and the costs of building and operating it. This chapter reports on the design and testing of all the highly engineered technical components. (See chapter 7 for the report of conventional facilities design.)

EVALUATION OF DESIGN WORK

An eight-member international panel of experts was commissioned by the Steering Committee to evaluate the results of the technical design work for the accelerator and to comment on the progress made, estimates of cost and overall readiness for decision.

The summary of the report of the evaluation panel states:

"The TRIUMF-KAON Project will provide a unique world class facility for basic research in particle and nuclear physics with performance capabilities which will not be available anywhere else. The committee unanimously agrees that the project is technically mature and urges that funding be secured to pursue the construction with the utmost urgency. The specific Terms of Reference are addressed in the following.

1. Technical Assessment of the Design

Although the total design is ambitious the basic concept of the design is simple and conventional — a 3 GeV synchrotron booster and a 30 GeV main synchrotron. To fully exploit the available beam intensity capability of more than 100 μA from the TRIUMF Cyclotron, each of the synchrotrons is preceded by a dc accumulating ring and the main synchrotron is also post fitted with a dc beam spill stretcher ring to make the unprecedented high intensity, high energy beam user friendly for experiments. The use of the TRIUMF cyclotron has been demonstrated to be technically feasible, more economical and, with time and experience considered, more reliable than any other newly constructed higher performance injector.

The designs of individual components have been competently pursued by the project staff. The difficult components have all been identified. These are:

- A-ring H^- stripper injection
- B-ring rf system
- B-ring and D-ring vacuum systems
- E-ring high efficiency slow extraction

Effective solutions to these difficult problems appear to have been found, although further improvements in the solutions are still expected.

The committee finds that the design of the high performance machine complex has been successfully tackled by a group of competent physicists and engineers.

2. Progress of R and D Projects in Support of the Design During the Past Year

Several important R and D projects have been pursued and significant progress has been made during the past year. These are:

- H^- beam extraction from the TRIUMF Cyclotron
- B-ring rf system, especially the novel configuration with perpendicularly biased yttrium-garnet tuners
- 1 MHz beam chopper for injection into A-ring
- B-ring magnet and power supply prototypes
- Development of the vacuum chamber systems for the B- and D-rings
- Prototyping of the injection and extraction kicker systems
- Theoretical investigation of the stripping injection into the A-ring and the slow extraction from the E-ring

Most of these projects have progressed to a point such that designs of systems producing adequate performance have been demonstrated. Their continuation will undoubtedly lead to further improvements of the designs.

3. Degree of Readiness

Traditionally, accelerator projects are approved, funded, and the construction staff, including the Project Leader, assembled as soon as one is convinced that solutions exist for all design problems. This is for the simple reason that the detailed, improved and finalized design must be done by the Project Leader and his construction staff. These personnel are usually available only after the project funding is secured. The committee considers that the present state of design of the KAON Project has already progressed beyond the threshold of readiness. The project now needs authorization and funding commitment so that the final construction Project Leader and staff can be attracted and engaged, otherwise the continued design effort will lose momentum.

In addition to continuing the current developments, the committee recommends:

- Prototyping of magnets and power supplies of all rings with focus on the reduction of the numbers of different types of these components.
- Optimizing the location and the design of beam loss collectors.

4. Cost, Schedule and Manpower

The costing of major subsystems of the KAON Project has been evaluated in depth. The estimates are in many cases based on quotations or budgetary estimates by industry, and experiences of other laboratories. We consider the cost estimates as presented in the Project Definition Study to be on a firm footing. The allowed contingencies of 10% for conventional construction and 15-20% for technical components are sufficient.

The proposed 5-year schedule appears to be very tight. This would be adversely affected by any difficulties in the funding, staffing or supplier delivery schedules.

The committee recommends an extension of the schedule by 1 year. This will not detract from the project's desirability in any way.

The manpower estimate is realistic. Personnel of proper quality must be found and brought to the project in a timely fashion."

We note here that while giving generally strong approval of the KAON Factory Design work carried out under this study, the Accelerator Review Committee does recommend an extension of the construction period for the project from five years to six years. Such an extension has many merits but it is not recommended at present by this Steering Committee nor is it envisaged in the construction schedules of Chapter 8. On the one hand, the extension is conservative: it allows a more orderly construction process, thus reducing risk, and it even ameliorates cash flow somewhat. On the other hand, it postpones the service so urgently sought by the world community and might be viewed abroad as Canada not taking up the challenge to demonstrate to the world that it can accomplish such a complex project in an exemplary fashion. There is room for boldness here and, on balance, we are in favour of an initial stance of boldness. However, the matter of the construction schedule must be subject to review by the construction leaders, as soon as they are in place. One should expect that the Canadian leaders of the project would continue to strike a pragmatic balance between scientific urgency and construction capabilities and risks. We recommend that a firm decision on a five versus six year schedule be taken soon after a decision to proceed with KAON, and in consultation with foreign partners.

SPECIFIC DESIGN RESULTS

For the accelerators, the aim of the study was to establish a high degree of confidence in the design, to build prototypes of critical items and to revise the cost and manpower estimates. The following paragraphs list the highlights of progress on the various projects. In the following subsection, we have not been able to spare the reader from all the technical jargon of the world's accelerator builders.

Accelerator Design

- To accommodate a slow extraction system of unprecedented efficiency, the shape of the Extender and other large rings has been changed from circular to racetrack. Computer tracking studies have shown that the use of an additional electrostatic deflector in the long straights can reduce the beam spill 10-fold to below 0.2%.
- The Extender will be located 4 meters horizontally outside the Driver, rather than 1 meter below it. This is convenient for installation and servicing and allows more space for local shielding in the extraction regions.
- The main tunnel is to be located to the west of the present buildings, rather than around them. This avoids congestion and provides more space for the experimental halls. This relocation, together with magnet lattice changes, have required the complete redesign of all beam transfer lines.
- Provision has been made for complete debunching of the beam in the Extender, as required for certain rare-decay experiments.
- The Booster quadrupole focusing magnets have been reversed to make injection and extraction easier.
- A new injection section has been designed for the Accumulator to provide a scheme for painting the narrow beam from the cyclotron over the much larger aperture, taking advantage of the development of stripping foils with two free sides.
- Detailed schemes have been developed for accelerating spin-polarized beams.
- To avoid beam spill due to coupling resonances the horizontal and vertical emittances are equal.
- Transfer line beam dumps are used in preference to fast abort systems.

Magnets

- Detailed magnetic field computations have been carried out to optimize the design of the Booster and Driver dipole (bending) and quadrupole (focusing) magnets.
- A fully specified prototype Booster dipole magnet has been designed and constructed. (Figure 3-1)

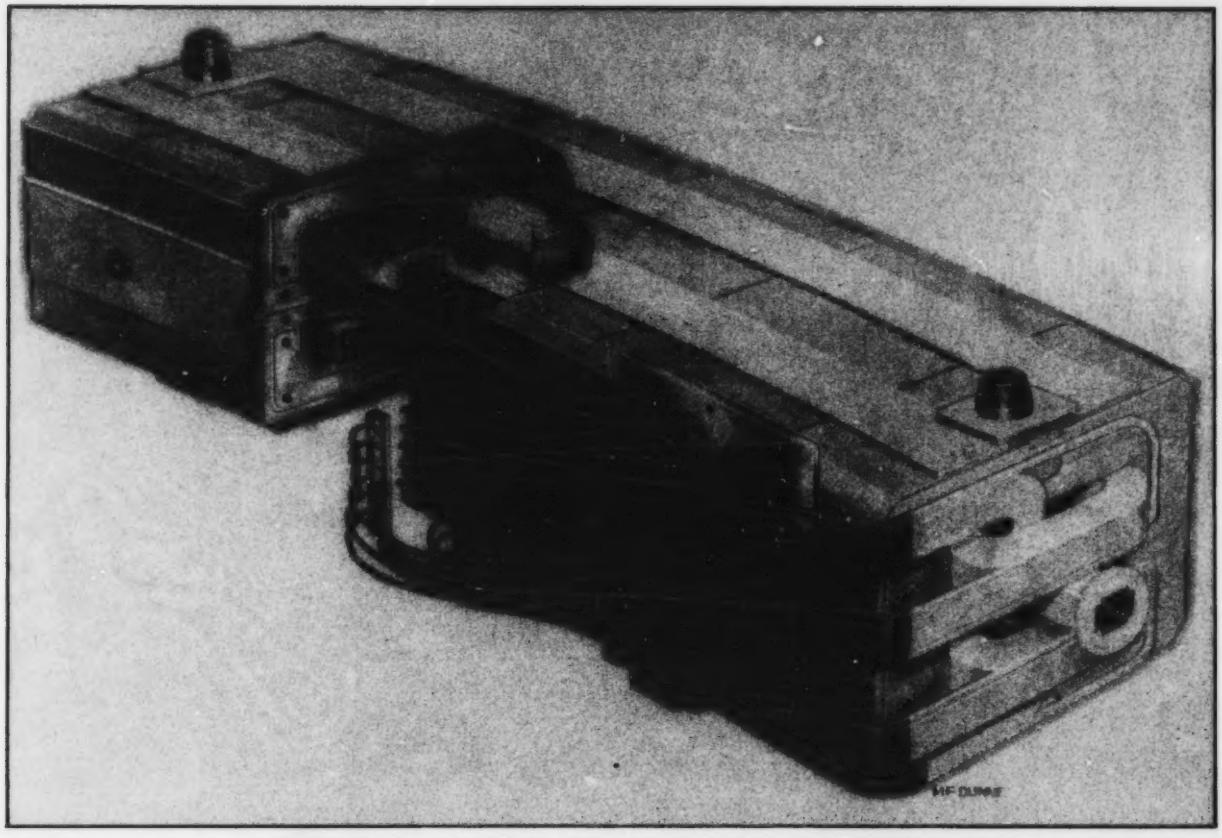

Figure 3-1 Booster Dipole Magnet and Ceramic Vacuum Chamber

- An approximate prototype Booster quadrupole magnet is under construction.
- A magnet measurement system with several testing stations and a capacity of 25 magnets per week has been designed to handle the maximum anticipated production rate.

Magnet Power Supplies

- The test stand using old magnets from the NINA synchrotron operated successfully at dual frequency, with the field rise times three times longer than the fall.
- A frequency-changing capacitor-disconnect switch has been designed.
- A power supply suitable for testing the Booster prototype dipole magnet at full power has been designed and delivered.
- The basic building block for regulated dc supplies was selected to be a 450 volt, 1000 ampere unit and one of these was constructed based on the chosen technique of high-frequency link power conversion.
- Multi-cell resonant circuits have been designed capable of powering all the dipole magnets in each synchrotron.
- The dc by-pass chokes have been designed in conjunction with Canadian industry. A combined choke for each cell is ruled out by size and weight, and so separate chokes would be used.

Kickers

These are pulsed ferrite magnets with rise times less than 100 billionths of a second, used to kick the beam into or out of a ring. (Figure 3-2)

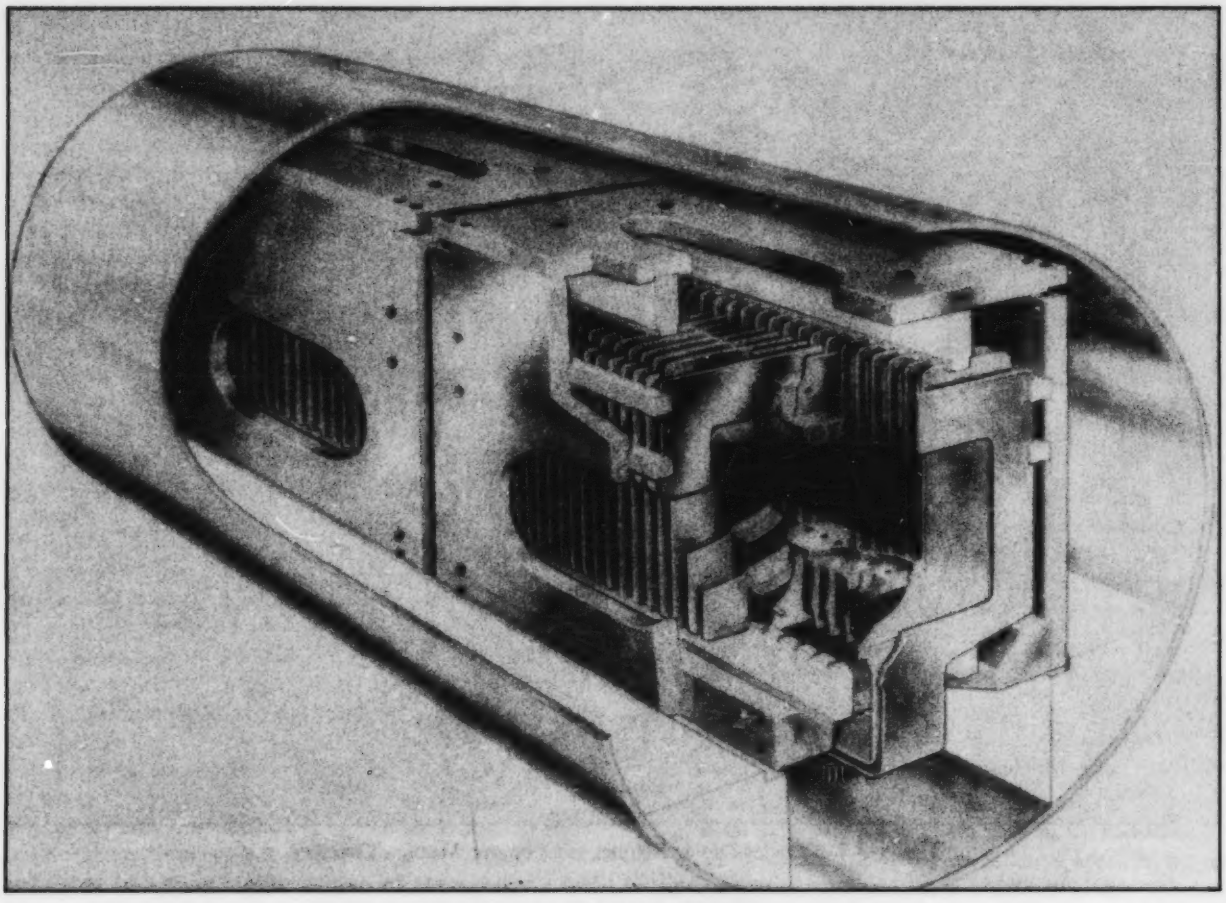

Figure 3-2 Kicker Magnet

- Two kicker magnets were obtained on loan from CERN and were carefully studied with regard to both their magnetic and mechanical design.
- A pulser was also obtained from CERN and its cycling rate successfully increased from 1 to 50 cycles per second. Sufficiently flat 40 kilovolt pulses were obtained, 600 billionths of a second long, with less than 30 billionths of a second rise and fall times.
- A kicker magnet suitable for operation with this pulser has been designed and built.
- A novel pulsed chopper has been designed and a prototype is being built. This device will be installed in the injection line from the cyclotron in order to deflect away 5 out of every 45 beam bunches. This will provide a gap in the beam 100 billionths of a second long in each ring for turning the injection and extraction kickers on and off. To do this a 30 kilovolt pulse of this length is sent to the strip line deflector every millionth of a second. The power requirement is drastically reduced by energy storage in a low-loss transmission line.

Radio-frequency Accelerating System

- A prototype Booster accelerating cavity was completed, based on that in operation at the Fermilab booster synchrotron. It was successfully tested at signal level over the entire frequency range (46-61 MHz) using air-cored tuners.
- An alternative prototype shown in Figure 3-3, developed at Los Alamos and shown there to give improved performance at fixed frequency, has been obtained on loan. This cavity has now been completely reconstructed at TRIUMF to allow the frequency to be swept over the full range 50 times per second; initial tests look promising.

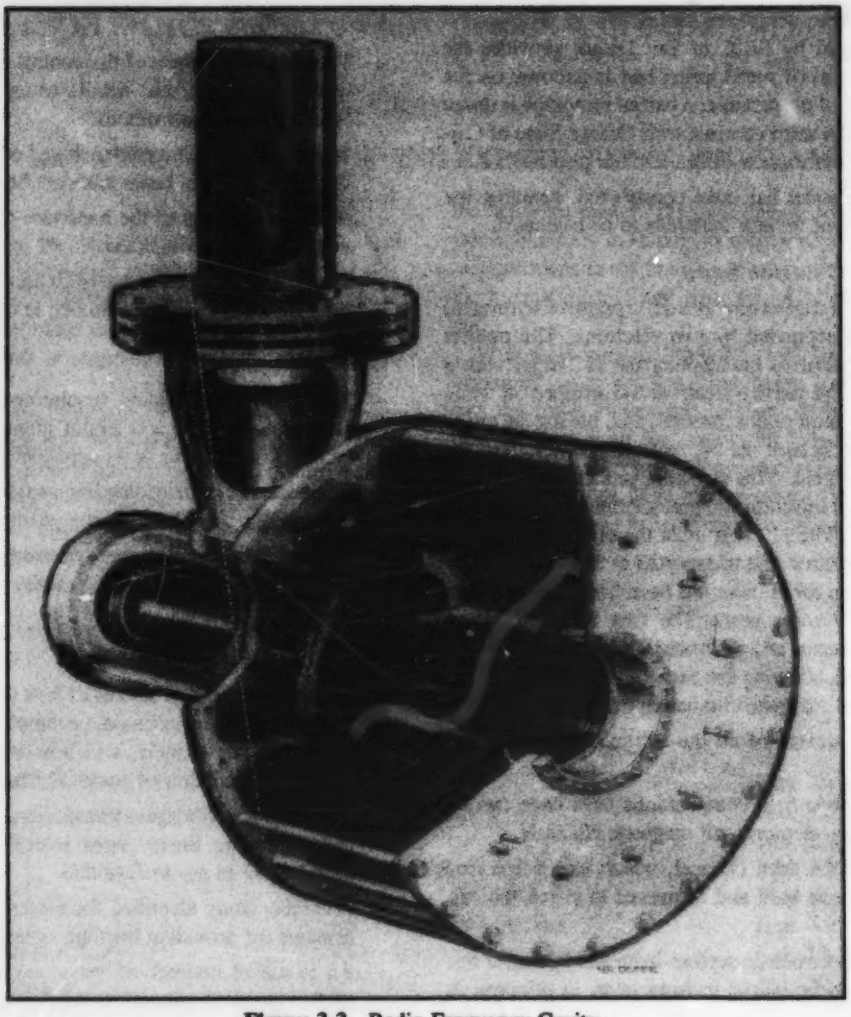

Figure 3-3 Radio Frequency Cavity

- A structure to damp higher-order modes in the Los Alamos cavity has been successfully tested at signal level. These modes could induce instabilities in both the beam and radio-frequency systems.
- Modified forms of the HERA proton cavities developed at AECL, Chalk River, are proposed for the other rings.
- A detailed theoretical study of beam loading has been carried out in order to gain a thorough understanding of the feedback loops needed to avoid instabilities induced in the radio-frequency system by the high beam power.
- Collaboration has been continued on the design of radio-frequency cavities and amplifiers with the Los Alamos and the Superconducting Super Collider groups in the United States.

Beam Pipe and Vacuum

- More stringent vacuum tolerances have been imposed to avoid beam instabilities.
- Pumping systems have been specified in detail for each of the rings and transfer lines.
- Ceramic vacuum chambers will be used within the fast-cycling magnets of the Booster and Driver in order to avoid eddy current heating and magnetic fields. These must, however, incorporate metallic "rf shields" to provide low-impedance paths for the image currents induced by the beam. Three contracts were placed for prototypes. The first was with the Rutherford Appleton Laboratory in the UK based on the design used successfully in the ISIS accelerator. This design, which uses an internal wire cage

as shield, has been completed and delivered. The second design, developed by SAIC in San Diego, provides the shield in the form of metal strips laid in grooves on the internal surface of the ceramic; a partial prototype is under construction. The third contract with Omega Slate of Calgary involves construction of the ceramic pipe only.

— A vacuum test stand has been constructed, enabling the outgassing rates of various materials to be evaluated.

Extraction of the Cyclotron Beam

The existing cyclotron accelerates H^- (negative hydrogen) ions — a proton surrounded by two electrons. The present extraction system involves intercepting the H^- beam with a thin carbon foil. In this the two electrons are stripped off while the much heavier proton passes through, and, having the opposite electric charge, is bent out of, rather than back into, the cyclotron magnetic field. This stripping process, however, is essential for efficient injection into the Accumulator over many thousands of turns. The H^- ions must therefore be extracted whole from the cyclotron and transported to the Accumulator. An extraction system for H^- ions has been under development at the cyclotron for some years. The first two elements, a radio-frequency deflector and electrostatic septum, had already been built and tested, showing that 90% of the H^- beam could be cleanly separated from the circulating beam.

— The layout and design of all the extraction elements has been finalized.

— Extensive magnetic field computations have been carried out for the 5 new elements, all magnetic channels.

— A prototype of the third channel, which uses some iron elements, has been built and measured to check the calculations.

— To protect the electrostatic septum from irradiation, a fine stripping foil can be placed in front of it, in principle at multiples of 120° upstream of the septum. Experiments have now confirmed that the 120° shadow is indeed stable enough to protect the septum.

— A test of the electrostatic septum at full beam intensity, which had been planned for fall 1989, was postponed because of the cancellation of the regular cyclotron shutdown. It will now take place in spring 1990.

Control System

— The logical structure of the control system has been analyzed in considerable detail, using Structured Analysis Structured Design methods.

— The hardware architecture is based on a local area network supporting control buses and data buses.

— A thorough study of the hardware and interface requirements has been completed.

— The synchronization of the rings and the timing of transfer between them have been studied in detail.

Shielding

— The transverse shielding requirements for the maximum allowed spill in the accelerator tunnels was determined to be 8 metres of earth or an equivalent density of concrete.

— The necessity of providing low-sodium concrete for tunnel construction and shielding was identified.

— The use of beam collimator systems to localize beam losses in the accelerator rings to specially shielded regions was examined.

Systems Integration

This activity involved studies of how the various accelerator components would be installed, powered, serviced and aligned in the accelerator tunnels, and how this would impact the tunnel size and location of equipment buildings.

— Designs for two magnet transporters with capacities of 18 and 30 metric tonnes were selected based on a towed vehicle now in use at Fermilab.

— A cabling study identified the preferred conductor configurations for providing the high current to the magnets.

— An in-tunnel network of surveying monuments tied to a surface geodetic network through a number of surface-to-tunnel penetrations were specified to provide alignment of magnets to the necessary tenth of a millimeter tolerance.

Chapter 4

KAON FACTORY SCIENCE AND EXPERIMENTAL PROGRAM

INTRODUCTION

The scientific case for building the KAON Factory was described in the initial proposal in 1985 and has been strongly endorsed by the NRC/NSERC Technical Panel and Review Committee and many other subsequent bodies. An important part of this study was to organize a series of workshops to discuss the science.

These workshops had three aims. First, to review and update the scientific case for KAON to take into account developments in nuclear and particle physics which had occurred since the writing of the original proposal. Second, to define the experimental facilities and buildings which would be needed to take full advantage of this powerful new tool for exploring the nature of matter. Third, to engage the international scientific community in helping to specify what are the most important questions to ask in terms of what experiments should have the highest priority and what would be needed to carry them out.

With these aims in mind the workshops in Table 4-1 were organized. Each had a specific theme, a scientific topic which was the focus of interest. Internationally recognized experts devoted their time and energy in helping us to update the scientific case and specify the experimental requirements. Four of the workshops were held overseas (two in Japan, one in Germany and one in Italy) in accordance with the third aim.

Table 4-1, KAON Factory Science Workshops

TOPIC	LOCATION	DATE
Rare Kaon Decays and CP Violation	TRIUMF	Nov. 30 - Dec. 3, 1988
Spin Physics	TRIUMF	Feb. 15-16, 1989
Hadron Spectroscopy	TRIUMF	Feb. 20-21, 1989
Joint JHP/KAON	KEK, Japan	Apr. 3-4, 1989
Neutrino Physics	Montreal	May 14, 1989
Physics at KAON	Bad Honnef, W. Germany	June 7-9, 1989
Hypernuclear Physics at KAON	KEK, Japan	June 17-18, 1989
Spin and Symmetries	TRIUMF	June 30 - July 2, 1989
KAON Users	TRIUMF	July 10-11, 1989
Lower Energy Muon Science at Large Accelerators	TRIUMF	July 19-21, 1989
Intense Hadron Sources and Antiproton Physics	Turin, Italy	Oct. 23-25, 1989

URGENT QUESTIONS FOR SCIENCE

The primary result of the series of international workshops was to show that the scientific motivation for building the KAON Factory is now even stronger than when the proposal was first written. The original questions which KAON was intended to answer have become, if anything, even more urgent and new questions have arisen which were not apparent in 1985.

Challenging the Standard Model

The new theory which describes the basic building blocks of nature, the quarks and leptons, and the forces between them is called the Standard Model. Developed over the past two decades, it received resounding experimental confirmation with the discoveries of the W and Z particles mentioned in Chapter 1.

Since that time it has been experimentally tested in ever more stringent ways and no breakdown has yet been found. Physicists believe, however, that the Standard Model must necessarily be incomplete, since it fails to explain many factors of the world in which we live. For example, it does not even attempt to explain the masses of the quarks and leptons, or the reason for the existence of the three families of fundamental particles. It is likely therefore, that the Standard Model

is but a fragment of a more complete picture, which has yet to be discovered and which will explain those features of the Standard Model which are at present arbitrary. The most urgent task of subatomic physics is to discover this more complete picture or theory. It is a main motivation for building the SSC, HERA and the KAON Factory.

The way in which physicists conduct this search is to look for new phenomena, which cannot be explained by the Standard Model and which would give glimpses of the more complete picture. To look for new phenomena one must conduct experiments which test the Standard Model in new ways. This can be done by either going to hitherto unreachable energies, as will be done at the SSC, or by carrying out experiments at more modest energies with unprecedented accuracy. This would be the approach of the KAON Factory, which would give information which is unique but complementary to the results of SSC experiments.

Time Asymmetry

As an example, it has been known for many years that in certain decays of the kaon, nature is not symmetric with regard to the direction of time. It is also known (as was first pointed out by Andrei Sakharov) that this symmetry is connected with the fact that the universe consists overwhelmingly of matter, and not of equal parts matter and antimatter. This time asymmetry therefore lies at the very root of the existence of galaxies, stars and ultimately ourselves, and yet its origin remains profoundly mysterious. It will be one of the most urgent tasks of the KAON Factory to carry out experiments to explore more fully the kaon decays in which the time asymmetry is manifest, and hopefully shed light on its origin. Such experiments cannot be carried out at the SSC, and the question becomes even more important.

Probes of the Nucleus

A second example, this time for nuclear physics, is the use of kaons as probes of the nucleus. It has long been known that the kaon has two features which would make it uniquely valuable as a nuclear probe. Firstly, it carries the strange quark, which acts as a kind of label or flag, rather like the radioactively labelled elements used in chemistry, biology and medicine. One can, in a certain sense, follow the kaon as it enters a nucleus. Secondly, the positively charged kaon is able to penetrate deep into the nuclear interior, enabling physicists to use it to explore the arrangement and nature of the particles which make up the nucleus. The aim here is to reach for evidence of the quarks and gluons which are known to make up the protons and neutrons, conventionally pictured as nuclear constituents, and to look for new types of particles in the nuclear interior. All this has been known for many years but hitherto kaon beams have been too weak to adequately illuminate nuclear targets, so the study of the nuclei using the kaon as a probe is still in its infancy. There is however, enormous interest, particularly in Japan and Europe, in this aspect of the KAON Factory Experimental Program.

Antimatter

As a final example, we take the physics which can be explored with antimatter. The KAON Factory would be by far the most intense source of antiprotons in the world. The European physics community, which has been at the center of antiproton physics in recent years, is extremely enthusiastic about the prospects of being able to carry out studies with the higher energy, more intense antiproton beams which will be available at KAON. Such studies would range from using antiprotons in testing the fundamental symmetries found in nature to their use in creating extreme conditions of temperature and density inside nuclei.

INITIAL SCIENCE PROGRAM FOR THE KAON FACTORY

The previous examples are chosen from a long list of topics explored in depth at the workshops and listed as opportunities in Table 4-2. Based on the workshop conclusions, a representative set of experimental halls and beamlines were designed, the layout of which are shown in Figure 4-1. These designs would allow beams of kaons, pions, antiprotons and polarized protons to be utilized in carrying out a full program of experiments to exploit the unique potential offered by the KAON Factory.

Table 4-2: KAON Factory Physics Opportunities and Requirements

Rare Decays	K^0, stopping K^+
CP Violation	few GeV/c K^0
Neutrino Physics	1-2 GeV neutrinos
	beam stop neutrinos
Meson Spectroscopy	8-15 GeV/c $K^\pm$
	up to 20 GeV/c $\pi^\pm$
Baryon Spectroscopy	0.5-2.5 GeV/±c $\pi^\pm$
	1-6 GeV/c $K^\pm$
Kaon-Nucleon Scattering	0.3-2.5 GeV/c $K^\pm$
Kaon-Nuclear Reactions	0.3-1.0 GeV/c $K^\pm$
Hypernuclei	0.3-2.5 GeV/c $K^\pm$
	1.0-1.5 GeV/c $\pi^\pm$
Spin Physics	3-30 GeV/c $\bar{p}$
Antiproton Physics	0.5-10.0 GeV/c $\bar{p}$
Low Energy Muon Physics	Low Energy $\mu^\pm$

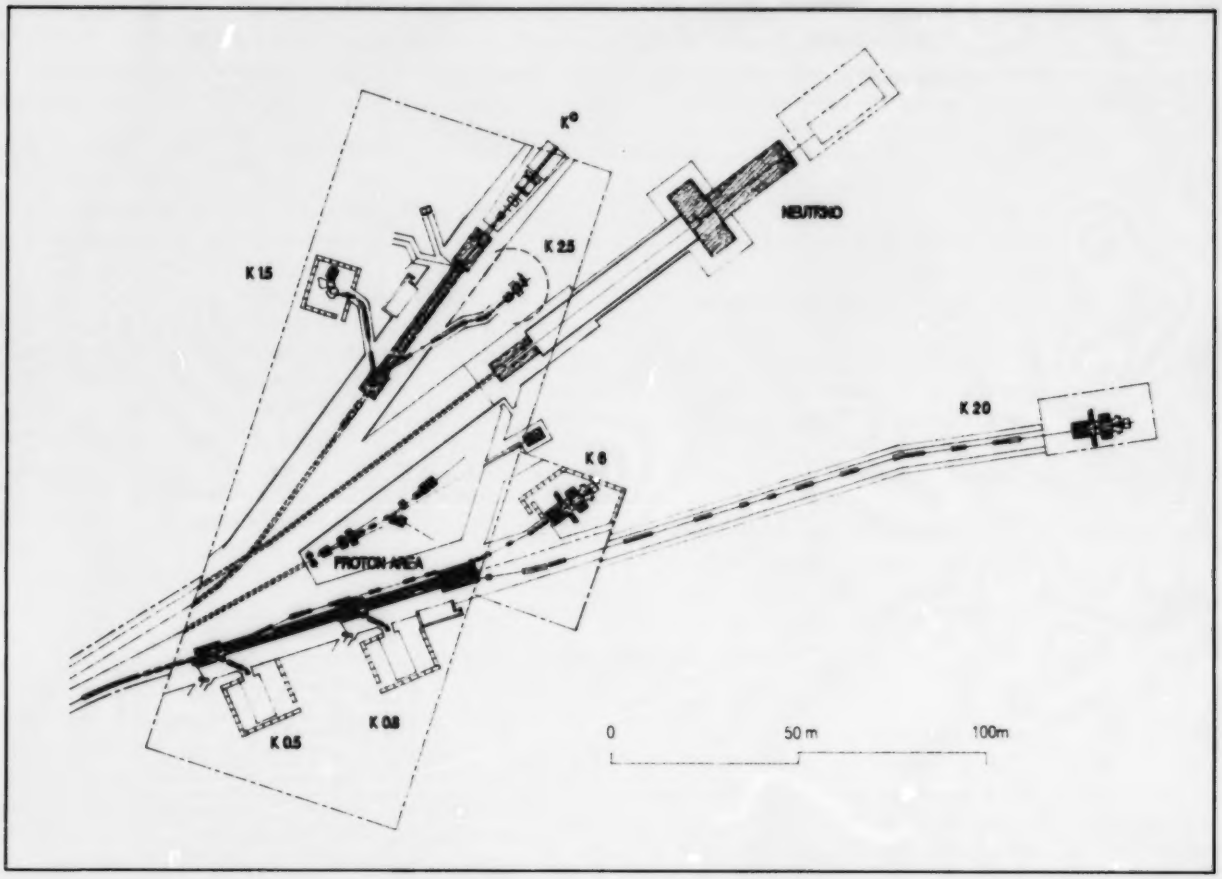

Figure 4-1 Experimental Hall and Beamlines

In an experimental facility with the range of possibilities of KAON (as indicated on Table 4.2), it is neither possible nor desirable that all of the experiments begin as soon as the machine is ready. The choice of initial experiments depends on many factors. Some experiments follow an orderly progression of complexity; some (e.g. neutrino experiments) await development of full intensity; some (e.g. spin physics) await the orderly refinement of beam quality. At each stage of evolution of the facility it is scientific priority, as determined by the large world community involved in the experiments, which make the critical program choices.

The main experimental hall, together with the beams within it, would be available for the initial experimental program. The precise nature of this program would depend on decisions made by an international panel of scientific advisors, as is usual for this type of facility, but might typically consist of the following set of experiments.

1) Study of Time Reversal Violation
2) Test of the Standard Model
3) Study of strange quarks in nuclei (hypernuclei)
4) Measurements with antiprotons
5) Probing the nucleus by scattering of K mesons
6) Study of systems of quarks and gluons (hadron spectroscopy)

To accommodate these classes of experiments, a set of secondary beamlines has been specifically designed and the experimental hall designed to accommodate the beamlines, experimental equipment and their associated support equipment. The properties of each separated beam are shown in Table 4-3. The intensities anticipated for the various particles in each beam are shown is Table 4-4.

Table 4-3 Properties of Separated Beams at KAON

Channel	Momentum [GeV/c]	Solid Angle [msr]	Momentum Accept. $\Delta p/p$ [%]	Length [m]	Type of Separation
K20	20-6	0.1	1	160	RF, 3 cavities 2.8 GHz
K6	6-2.5	0.08 - 0.30	3	110	RF 3 cavities 1.3 GHz
K2.5	2.5-1.25	0.5-2.0	4	54	DC, 2 stages
K1.5	1.5-0.75	2.0	4	30	DC, 2 stages
K0.80	0.80-0.55	6.0	5	18	DC, 2 stages
K0.55	0.55-0.40	8.0	6	14	DC, 1 stage, extra optics

TABLE 4-4 Anticipated Beam Intensities

Channel	Momentum GeV/c	K^- 10^6/s	K^+ 10^6/s	π^- 10^9/s	π^+ 10^9/s	$\bar{p}$ 10^6/s
K20	21	0.75	29	0.16	0.95	0.05
	18	2.4	43	0.35	1.05	0.35
	15	5.9	62	0.60	1.50	1.7
	12	9.2	52	0.90	1.90	5.0
	9	7.9	23	0.70	1.30	10.5
	6	2.3	4.2	0.78	1.20	11.5
K6	6	15	34	1.9	3.6	23
	3	2.5	4.5	3.2	5.0	43
K2.5	2.5	66	119	16	24	110
	2.0	39	76	21	30	91
	1.5	14	27	25	36	52
	1.25	5.4	9.7	27	37	26
K1.5	1.5	193	366	49	69	81
	1.2	52	93	36	49	25
	1.0	18	31	27	36	8.3
	0.8	3.7	6.3	18	23	1.9
K0.8	0.8	99	203	87	113	7.1
	0.65-	32	59	63	80	2.6
	0.55	10	19	44	55	1.0
K0.55	0.55	41	80	80	101	1.5
	0.50	21	44	67	82	0.93
	0.45	9.2	21	50	61	0.53
	0.40	3.8	9.4	33	44	0.30

*Intensities are for a 100 μA 30 GeV beam on a 6 cm Pt target

As future funds become available to add the neutrino line, polarized protons and high energy kaons, this list could grow to encompass the full range of science which would be explored.

KAON SCIENCE PROGRAM IN CONTEXT OF PHYSICS AND FACILITIES

As stated earlier, nature's fundamental constituents appear to be the quarks and the leptons with their associated neutrinos. The early experiments at the LEP machine in CERN Geneva, and the Stanford Linear Collider, indicate that only three families of quarks and leptons exist. It is therefore known exactly how many constituents must be sought experimentally; currently the only missing ingredient is the 'top' quark.

These quarks and leptons experience the forces of nature by the exchange of particles or quanta. For the electromagnetic force the exchanged particle is the massless photon; for the Weak force, there are the massive W and Z particles, and for the Strong or Nuclear force the exchanged quantum is the massless gluon.

Figure 4-2 shows the mass of all these particles plotted against their electric charge in units of the charge on the electron. While mass is well defined for leptons and exchanged particles, it is not so easily defined for the quarks, which cannot exist individually in the laboratory. The "mass" scale in the figure is then in some sense merely "to guide the eye."

Figure 4-2 also shows the number and range of facilities, either existing, approved or proposed, which are available to the international community of subatomic researchers. Many of them are "factories" specifically to produce in quantity one of the major particles. The figure places the KAON Factory neatly within the world network of facilities and physics.

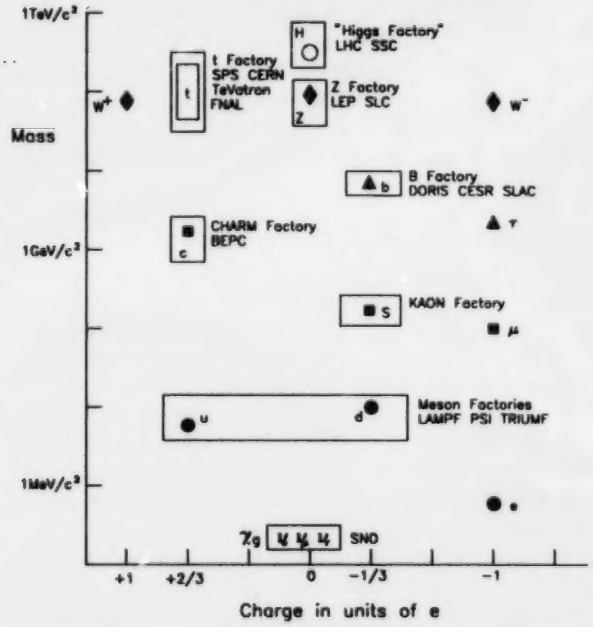

Figure 4-2 The New Physics and the New Factories

The facilities which are or will make up the world network may be summarized as follows:

1. Hadron Colliders (SPS at CERN, Tevatron at Fermilab)
   These machines are the only ones currently functioning at which the 'top' quark may be discovered. They are shown as 'top' factories even though they have not yet produced a single top quark.
2. HERA at DESY
   This facility is not depicted directly, but it uses intense sources of W and Z particles and photons to probe the quark structure down to distance scales not previously accessible.
3. The Supercolliders (SSC & LHC)
   The Standard Model lacks one important particle, the Higgs particle, which plays a crucial role in breaking nature's symmetry and giving different masses to the constituents and exchange quanta. Its mass is believed to be less than 1 TeV/c^2. This mass scale sets the design goal for the SSC in the United States and the proposed Large Hadron Collider (LHC) in Europe at CERN.
4. LEP at CERN, SLC at Stanford
   These machines are Z-factories. The detailed study of Z-decays checks the Standard Model with greater precision than ever before.
5. B-Factory
   There is intense competition to become the world's B-Factory among the Cornell Laboratory CESR, the Stanford SLAC facility in the United States and DORIS in the DESY laboratory in Germany. The b-quark has many interesting decays and can shed new light on the question of time asymmetry, complementary to the experiments at KAON.
6. Charm Factories
   The new Chinese accelerator at Beijing (BEPC) and a proposed Spanish facility will be the world's intense sources of charmed quarks and also of tau leptons.
7. The KAON Factory
   As stated, the machine would be a copious producer of kaons which contain the strange quark. It would also be a copious source of antinucleons, neutrinos, hyperons, pions, etc.
8. The Meson Factories (LAMPF, PSI, TRIUMF)
   These machines have provided more than 10 years of intense beams of pions, made from 'up' and 'down' quarks. They also yield intense beams of muons which arise when pions decay.

Note: In addition to these accelerator and factory facilities, the Sudbury Neutrino Observatory (SNO) will be a specialized detector which, in its final form, will respond to each neutrino species using the sun as a well-understood source. It is included here because of its importance and its Canadian context.

The next couple of decades should see all of these facilities playing their complementary roles in trying to answer the question as to "What lies beyond the Standard Model", or more generally, "Why are we here?"

Chapter 5

INTERNATIONAL SUPPORT

PURPOSE

Foreign participation is a key element of the KAON Proposal. The purpose of the international consultations component of the study was:

a) to inform foreign governments, scientists, and the private sector of the KAON Factory Engineering Design and Impact Study and keep them apprised of its progress;

b) to communicate to potential international partners and interests the specific requirements for parts of the facility/ operation that could be provided from non-Canadian sources; and,

c) to determine the extent of foreign governments' interest in participating

RESULTS

Foreign participation is essential for KAON to proceed. Of the 800 scientists expected to work at KAON, two-thirds would come from abroad, and one third would be from Canada. TRIUMF/KAON staff had estimated that foreign participation in components valued at $200 million was a reasonable target. Based on the number of foreign scientists expected to be working at KAON, it was proposed that about one half of foreign contributions ($100 million) would be appropriate from the United States; the balance would be split equally between Europe and Japan.

The proposed mode of participation, contributions in the form of components manufactured by the participating countries, was successfully used by German scientists for their accelerator in Hamburg called HERA. This mode is appropriate where the facility has unique characteristics attracting wide international interest, and where scientists from the host country would be in a minority. The KAON Factory falls into this category.

A delegation, established under the Canada-British Columbia Agreement on the proposed KAON Factory Engineering Design and Impact Study, visited selected countries to determine their interest in the project; formal indications of participation were the desired outcome.

Given that Canada had not made a commitment to KAON, the delegation might only have expected to obtain expressions of general interest from foreign partners. The physics communities in several of the countries consulted, however, had shown strong support for KAON and had expressed this support to their own funding agencies. As a consequence, government officials in a number of countries provided substantive responses, far more than expressions of interest. It must be emphasized, however, that all the responses express intentions; commitments can only be obtained after Canada has committed to KAON. Extensive negotiation will be needed to transform intentions to commitments.

Written responses to proposals for participation have been obtained from all countries consulted, with the exception of Japan. The responses from Germany and the United States, two key participants, are as positive and substantive as could be expected in the context of these consultations. The United States Department of Energy has indicated its intention to request in its budget submission funding for $100 million (Canadian) over five years. German laboratories intend to participate in KAON at a level which at least matches Canada's earlier contribution to the German HERA accelerator. With these two key responses, other letters and communications, there are reasonable expectations that the total participation which can be negotiated could be close to the $200 million target. In the context of these consultations, this is a successful outcome.

ALTERNATIVE MODES OF INTERNATIONAL PARTICIPATION IN SCIENCE

Three models for international participation in major science projects were open for discussion. They were:

a) The "CERN MODEL", in which a number of countries pool resources, through some appropriate formula, and jointly have legal and financial control. Member nations have a long term and relatively open-ended commitment to the continuing project. This model was pioneered by European countries for the international laboratory called CERN.

b) The "NATIONAL PLUS MODEL", in which a single host nation dominates the science but invites other nations to participate. Because the host nation dominates, it usually does not require commitments from foreign partners before making its own funding decision. Examples include the Superconducting Supercollider (SSC) in the United States and the existing TRIUMF facility in Canada.

c) The "HERA MODEL", applies to projects which are intrinsically international — no nation dominates the science; it is an alternative to the CERN model. The host nation provides the bulk of construction and operating costs of a major new project while retaining legal and financial control. The majority of scientists and experiments are from abroad. Foreign countries are invited to make substantial contributions to project construction and are invited to participate in advisory bodies relating to the construction phase and the experimental program. This model was developed by the Federal Republic of Germany for the HERA project in Hamburg.

Since the Canadian KAON Factory would be a unique, world-class facility, and Canadian scientists would be in the minority, the 'National Plus' model would be inappropriate for KAON. The 'CERN' model, which requires long term commitments to operating and infrastructure costs, was seen as being difficult to launch internationally at the present time. The HERA model emerged as being plainly most applicable for the KAON Factory.

SEQUENCE OF EVENTS TO ESTABLISH INTERNATIONAL PARTICIPATION

The sequence of events for consultation and negotiation in establishing a project organized under the HERA model is as follows:

- A host country proposes a large new project originating from its existing excellence in the field.
- The host country explores the interest of foreign partners in the project. (Canada did this with the Hanna Committee which visited five G-7 nations in 1987.)
- The host country indicates its serious intention with regard to the project (The G-7 nations indicated that Canada's commitment to the present study would serve this purpose.)
- With this statement of serious intent, the host country consults in some detail with potential partners on the form and extent of their participation. **The present consultations constitute this step for KAON.**
- On the completion of its consultations and other necessary studies, the host country makes a decision about whether or not to proceed with the project.
- After a final decision to proceed, the host country formally negotiates the contributions from abroad, based on earlier consultations.

DISCUSSION

With the HERA model as the frame of reference, a delegation established under the terms of the Canada-British Columbia Agreement visited selected countries to carry out the appropriate detailed consultations. As indicated in the Agreement, formal indications by foreign governments that they would be prepared to participate in the project would be a desirable output of the consultations.

During the KAON consultations the British Columbia members of the delegation emphasized the provincial interest and commitment to KAON. At the same time, it was made clear that KAON was not, at this time, an approved, committed project and that the Government of Canada would make its decision following completion of the KAON Engineering Design and Impact Study which includes this analysis of the potential for foreign participation.

In broad outline the consultations confirmed:

- That KAON would be a unique, world class facility addressing important areas of nuclear and particle physics. Worldwide, only one such facility would be built.
- That some two-thirds of the scientists working at KAON would come from the countries consulted.
- That international participation in the project was both appropriate and necessary.
- The need for Canada to make an early decision on KAON construction.

The principal issue in all countries was the extent to which the funding sought was available in current budgets and, if not, whether there was a reasonable probability of obtaining increased funding for participation in KAON.

Because Canada has not made a commitment, written responses received are cautiously phrased and conditional. Clearer and more positive answers would probably be obtained when Canada has made a commitment to KAON. The responses, summarized below, nevertheless set clear terms of reference and boundary conditions for negotiations with participating countries following commitment by Canada.

The positions established were, in brief:

United States of America

The U.S. Department of Energy has indicated its intention to request in its budget submission, funding for KAON at $100 million (Cdn) over five years. This response is the strongest possible within the context of these consultations. The U.S. budget request requires early Canadian commitment to KAON. Budget approval may require political representation at several levels.

Germany

With the explicit endorsement and support of the German Ministry of Research and Technology, the two key German laboratories are prepared to contribute to KAON at a level which matches Canada's earlier contribution to HERA. Skilled manpower, a crucial element, would form an additional part of German participation.

France

Participation at a low level could be funded from current budgets. French estimates of the number of their scientists who might work at KAON suggest that participation at a more significant level might be justified and funded if other projects currently under consideration by French officials were deferred or cancelled. A more substantive response could be expected if KAON is approved.

Italy

The Italians face severe budgetary constraints and have to plan for a number of proposed projects which compete for funds with KAON. Participation at a low level could be funded out of current budgets. This amount could be increased if some of the key competing projects were to be delayed or cancelled. Again, a more substantive response might be expected if KAON is approved.

United Kingdom

The U.K. has severe budgetary constraints, and in addition, KAON does not fit within current U.K. scientific priorities. The U.K. is consequently unable to contribute to components for KAON construction. It is anticipated, however, their design assistance will continue.

European Economic Community

There are possibilities for participation; discussions are still at a preliminary stage.

Japan

No response can be expected until Canada has made a commitment. The KAON Factory Project has strong support from the Japanese nuclear physics community. Based on the consultations, it is possible that, with clear expressions of intentions to participate in KAON from other countries (which we now have), and a commitment by Canada, Japan might be prepared to participate in KAON. The proposed level of participation itself ($50M) did not seem to be an issue. With careful negotiation by Canada following its commitment to KAON, there appears to be a reasonable possibility of obtaining Japanese support at the proposed level.

Korea

The response from the Republic of Korea indicates possible participation in the range of $6-12 million, but support is conditional on a contribution from Korean industry. Korean officials are commissioning a study to assess relevant industrial expertise and benefits to Korean industry from participation in KAON. The results of the study are expected within a few months.

Other Countries

Scientists from other countries, such as Israel, China, and the U.S.S.R. are interested in KAON science. These countries could be approached at a later date for possible contributions.

SUMMATION

The current dollar value of possible support can be summed as: U.S.A. $100M; Europe $17M to $31M; Japan some $50M; for a total of $167 to $181M. This summation excludes: possible contributions from Korea ($6M to $12M), from the European Community, from other countries not included in the consultations; the possibility of increased participation from Italy; the value of seconded design staff from Germany; and, contributions for experimental equipment.

It must be recognized that there are still many uncertainties inherent in the present consultations by Canada which will be resolved only by negotiation. None of the contributions are assured in any absolute sense. There is, nevertheless, reasonable expectation that the total participation which can be negotiated would be close to the $200 million target. This outcome, a success in the context of these consultations, is a consequence of the interest and support for KAON science by the subatomic physics communities in other countries.

Chapter 6

CANADIAN INDUSTRIAL CAPABILITY

PURPOSE

KAON Factory construction would require an extensive range of high technology components. Canadian industrial participation in supplying KAON requirements offers the potential for industry to enhance its technical prowess and international trading competitiveness and open new export markets. To fully define Canada's industrial development opportunity which KAON offers, a number of objectives were set for the industrial capability component of the study:

Identification of Canadian industrial potential; that is, firms across Canada interested in supplying KAON requirements;

Identification of Canadian industrial capability; that is, firms who can meet the exacting technical specification for delivery of KAON components;

Identification of priority technologies — those technologies which are strategic priorities for Canada to pursue in the context of world markets;

Assessing the implications of priority technologies on Canadian industrial development and for the KAON procurement process;

Developing possible mechanisms for achieving strategic benefits for Canada.

Table 6-1 High Technology Component of KAON Factory

Technical Component Category	Estimated Procurement Requirement: [$million]
Magnets	87
Kicker Magnets	27
Radiofrequency Stations	27
Power Supplies (for all areas)	100
Beam Pipes and Vacuum	35
Remote Handling	14
Control Systems & Instrumentation	85
TOTAL	375

Note: All values are in 1989 dollars

KAON HIGH TECHNOLOGY REQUIREMENTS

Construction of the KAON Factory would require two general types of construction; conventional and technical. It has been assumed that the requirements for conventional construction such as buildings and tunnels can all be provided from Canadian sources. This assessment of Canadian industrial capability examines the requirements for technical construction which involves procurement of high technology components valued at about $375 million as shown in Table 6-1.

This analysis of industrial capability focuses on these high technology areas because it is here where Canadian capability, in some cases, was deemed to be questionable, given the high tolerances and specialized requirements for KAON. Supply of these high technology components cannot, in many cases, come from off-the-shelf inventories or production processes. For example, the KAON Factory would require higher than normal standards which can serve to encourage supplying industries to refine and develop new production capabilities. The spinoff benefits from this procurement are well illustrated by studies of similar benefits attributed to the European organization for nuclear research (CERN) in Switzerland, a facility of significantly larger size and similar technology. There it was found that the European industrial community markedly enhanced their competitiveness in world markets because of the incentive for all companies to improve their products.

INDUSTRIAL LIAISON PROGRAM

KAON offers the potential for firms from all regions of Canada to participate in supplying high technology components. This assessment process established a formal liaison program with provincial and federal representatives in each province to participate in the identification of interested and/or potentially capable firms. Preliminary lists of firms generated in cooperation with these representatives provided the basis for an extensive series of surveys, interviews and, in some cases, site visits by the industrial capability study team to compile information on the firms' interest and technical capability. Prior to inclusion in the Canadian industrial potential database, the listing was reviewed by provincial and federal representatives in each respective province.

IDENTIFICATION OF POTENTIAL CANADIAN SUPPLIERS

Four hundred and twelve firms from across Canada were identified as potential suppliers to KAON from the industry

liaison program. Starting with this base, the firms were subjected to a rigorous classification based on the information which they supplied to determine their technical capability to meet KAON requirements. The classification system includes six categories:

1) Prime contractor: able to supply complete assemblies of major components (e.g. one type of magnet or power supply).
2) Key subcontractor: necessary to supply critical portions of those major components (e.g. steel laminations for magnets, or tetrodes for RF amplifiers).
3) Other subcontractor: less technically competent subcontractors, plus those providing smaller components or low-tech components (e.g. electrical cables or control equipment racks).
4) Interested / Not Qualified Contractors: Those who explicitly indicated interest but were not judged qualified to participate in the KAON procurement process.
5) Not interested: those firms who were nominated but explicitly indicated no interest in supplying to the KAON Factory construction.
6) Contacted / No Response: those firms were nominated but who did not respond and did not provide information after a minimum of three contacts by the study team.

In almost all cases, follow-up interviews and contacts were made with the firms to refine the study team's understanding of their capabilities, not just in the general technology areas described above, but also in specialist component areas within each technology area.

A total of 199 firms/plants throughout Canada were identified as capable of providing either prime contractor of key subcontractor service to KAON construction. Table 6-2 shows the geographic distribution of the firms by class of major contractor.

Table 6-2 Distribution of Potential Key Contractors

Contractor Class	Province										Canada Total
	BC	Alta	Sask	Man	Ont	PQ	NB	Nfld	NS	PEI	
Prime	11	3	0	4	16	13	0	0	0	0	47
Key Subs	52	10	5	4	59	21	1	0	0	0	152
TOTAL	63	13	5	8	75	34	1	0	0	0	199

CANADIAN INDUSTRIAL CAPABILITY

Assessment of Canadian industrial capability involved matching firms classified as prime contractors or key subcontractors against the specific requirements of the anticipated KAON procurement approach. Identifying industrial capability required the following analytic approach:

documentation of anticipated procurement practice for each technology area (details on contract structure, components required and preferred schedules for delivery);
a residual analysis for each technology area to identify whether there were sufficient, if any, prime contractors and key subcontractors to supply KAON in the schedule anticipated;
identification of areas of overlap and likely capacity restraints;
adjustment of the individual technology area results based on identified areas of overlap to derive industrial capability and capacity to supply KAON requirements in Canada.

OVERALL CAPABILITY

Canadian industrial capability was found for almost 85% of the high technology requirements of the KAON Factory construction. Assuming that Canadian firms were awarded to supply all these contracts, the estimated contract value amounts to about $340 million, (or $316 million when adjusted for non-Canadian subcontracting, see "Canadian Content" below).

The study found that there is no Canadian industrial capability in a set of technology areas whose total value is less than $40 million and includes some components for each of the following systems; kicker magnets, beam pipe and vacuum systems, radiofrequency and instrumentation.

CANADIAN CONTENT

The industrial capability findings demonstrate that Canadian industry is in an excellent position to service virtually all the KAON high technology requirements. Nevertheless, there are many firms classified as either prime or key subcontractors who are internationally owned or are agents for firms outside Canada. Analysis of probable Canadian content (Table 6-3) shows that an estimated 84% of KAON high technology contract value can be met in Canada.

Table 6-3 Canadian Content of Technology Contracts

Technical Component Category	KAON Contract Value [$million]	Estimate Canadian Content	Percent Canadian Content
Magnets	87.0	85.5	98%
Kicker Magnets	27.0	18.5	69%
Radiofrequency Systems	27.0	19.7	73%
Power Supplies	100.3	92.0	92%
Beam Pipes and Vacuum	35.4	24.7	70%
Remote Handling	14.0	13.1	94%
Control Systems & Instrumentation	85.0	62.4	73%
TOTAL	375.7	316.1	84%

POTENTIAL DISTRIBUTION OF CONTRACTS ACROSS CANADA

To illustrate one possible distribution of KAON high technology construction contracts across Canada, an overall estimate of provincial distribution was made based on the geographic distribution of capable firms and their technologies. The key assumption of current geographic distribution includes two general parameters:

i) all KAON procurement would be subject to competitive bid;

ii) no penalties would be assigned to bid prices for higher transportation costs for firms outside British Columbia.

Using this assumption, the distribution of firms is used to generate the distribution of expected value of KAON contract for each province shown in Table 6-4. The findings reveal that the expected value of the KAON Factory project would be greatest for Ontario, British Columbia and Quebec. Taken together, Ontario and Quebec could expect to capture more than 50% of the contract value in all high technology areas. The high performance of British Columbia is due in part to the location of the TRIUMF facility and the private sector contract work that it has generated in B.C. throughout its history. Note that the provincial distribution shown below are estimates, not targets or commitments, and they assume no intervention or industrial development in areas where Canadian capability is now weak.

Table 6-4 A Distribution of Contract Values

All Technologies	Province BC	Alta	Sask	Man	Ont	PQ	NB	Nfld	NS	PEI	Canada Total
% Distribution of Primes & Key	31	7	3	1	38	17	1	0	0	0	100
Contract Values [$M]	99	18	7.3	16	111	62	1.4	0	0	0	316
% Distribution of Contract Values	31	6	3	5	37	20	0.4	0	0	0	100

POTENTIAL CAPACITY SHORTFALLS

Capability notwithstanding, a number of areas where potential capacity shortfalls may be encountered were revealed by the residual analysis. Capacity shortfalls were defined as those instances where the residual analysis showed that more firms were required than were identified as capable for any given component, or that there was only one firm (or in some cases none) left after the residual analysis. This is a concern to the extent that, at the time of actual procurement, some firms may be too busy or simply not interested in submitting a bid for the relevant technology requirement. In these cases, KAON may experience capacity shortfalls even though the residual analysis has shown there are sufficient Canadian firms available.

This is not judged to be a significant problem given that a very conservative approach was taken to matching KAON procurement requirements/contract structures to available primes and key subcontractors. While for the purpose of analysis contracts were assumed to be allocated to individual firms, it is possible for one firm to assume more than one and therefore reduce potential for capacity problems. Similarly, it was found that there was no significant impact on capacity when analyzed for the effects of firms with more than one plant or with capability in more than one technology.

PRIORITY TECHNOLOGY ANALYSIS

The priority technology analysis considered factors such as spin-off benefits, non-commercial benefits, industry interest and ability, development risk, KAON incrementally and industrial sector dynamism.

The analysis of priority technologies indicates that about three quarters of the KAON Factory requirements are of high industrial importance to Canadian firms. Assuming that all high technology components were reserved for Canadian suppliers, the estimated value of the high priority technology contracts would be $274 million. Including the medium priority contracts would increase the value to $297 million or 79% of the total high technology value.

Priority technologies

The high priority areas of KAON technology requirements for Canadian industrial development are:

- Magnets
- Power Supplies
- Controls and software
- Remote Handling
- Ceramic beam pipe
- Radiofrequency amplifiers and controls

The medium priority areas of KAON technology requirements are:

- Fabrication of stainless steel beam pipe
- Radiofrequency components other than amplifiers and controls

The low priority areas were found to be the material for stainless steel beam pipe and kicker magnets because of limited spin-off potential; and, vacuum system components such as pumps because of intense existing competition among suppliers.

Special Emphasis in High Priority Technology Areas

Within each high priority area the analysis revealed areas where special emphasis should be placed, based largely on an assessment of export potential by Canadian firms and their competitiveness in world markets. Table 6-5 shows the areas for emphasis within each of the five highest priority technology areas.

Table 6-5 Special High Priority Technology Areas

High Priority Technology Area	Supply Area for Emphasis
Magnets	High Power Magnets Magnetic Circuit Designs
Radiofrequency Systems	Controls Amplifiers
Controls	All areas, Especially Systems Work
Remote Handling	All areas

ACHIEVING STRATEGIC BENEFITS FOR CANADA

A program of steps to ensure that potential strategic benefits of KAON to Canada are realized to the extent possible has been developed by matching the priority technology analysis results to the industry capability findings.

The major activities in the KAON strategic benefits program include:

1) Initial policy decisions on Canadian industrial involvement and procurement guidelines for KAON:
   - regional distribution
   - contract structures

followed by:

2a) Refining Canadian industrial capability assessment
   - update database of industrial potential
   - refinement of capacity analysis

concurrently with:

2b) Refining Canadian industrial benefits strategy
   - contract structure (size, tech transfer)
   - regional distribution policy
   - special regional programs (e.g Saskatchewan)
   - technology transfer office
   - selected technologies (e.g. controls)

and,

2c) Ongoing liaison information to provinces, federal government agencies and industry

Then bringing the capability and benefits work together by:

3) Finalizing procurement policy; and

4) Refining procurement approach
   - developing bid lists
   - finalizing contract structure.

5) Constructing the KAON Factory.

KAON FACTORY ENGINEERING DESIGN AND IMPACT STUDY

Chapter 7

CONVENTIONAL FACILITIES DESIGN RESULTS

PURPOSE

A component of the design and engineering work for the study was devoted to the refinement of conventional facilities for both design and costing purposes.

KAON is a complex project with major engineering activity in its design. For the purposes of this study, conventional is used to describe those facilities necessary to house and service the accelerator and experimental areas and includes:

- buildings
- tunnels and subgrade structures
- electrical power to site
- electrical power distribution
- water cooling system
- tunnel ventilation
- site services
- site development

KAON FACTORY REFERENCE SITE

The 1985 proposal prepared by TRIUMF was based on the main accelerator rings encircling TRIUMF with a developed site of over nineteen hectares. Early in the present study, the rings were changed from a circular configuration to race-track to accommodate a more efficient system for extracting the beam. This, in turn, achieves a mitigation of beam loss without which the full potential of KAON might not be realized.

This change in configuration created problems accommodating the main ring services. Other considerations such as the recent designation of the land to the east of TRIUMF as Pacific Spirit Park with its accompanying non-encroachment restriction, plus the need for more space to accommodate the experimental facilities caused alternative siting locations to be investigated.

The only effective solution placed the rings on University of British Columbia lands to the west of TRIUMF, resulting in a developed site of almost thirty-three hectares including the existing TRIUMF site. This site was selected as the reference design for the present study. However, agreement on the part of the University of British Columbia to allow a change in the usage of the lands in question remains a subject for future negotiations.

GEOTECHNICAL INVESTIGATIONS

A program of investigations was carried out across the reference site with six bore holes including piezometers in each hole and monthly monitoring over the period of a year. An additional program of multi-point piezometer analysis was carried out near the middle of the arc for the main ring. The results indicate subgrade complexities and further soil investigations will be required for detailed design and to delineate the water bearing zones for an efficient de-watering system design that will be required for all major excavations.

SUMMARY OF CONVENTIONAL FACILITIES

The following summarizes the conventional facilities, working from the Cyclotron vault through to the Experimental Hall.

1. IA Transfer Line

The IA transfer line is the beam line connecting the TRIUMF cyclotron with the Booster. This beam line is located partially in the existing Cyclotron vault with the majority in a new tunnel structure approximately 150 meters in length.

Work within the vault consists of new structural steel framing to support the beam line components and an overhead 7.5 tonne monorail crane. The north wall of the vault, some 2.2 meters in thickness, will be core drilled at two locations for passage of the beam pipe and for alignment sighting.

Once through the vault wall the beam line enters a cast-in-place concrete tunnel built in an open cut excavation which ranges in depth from 8 meters to 11 meters. The tunnel for the first 100 meters is a concrete arch with inside dimensions of 3.8 meters in width and 3.2 meters in height. Beyond this point the tunnel takes on a rectangular cross section 3.2 meters in height with the width varying as required to allow the magnet carrier to traverse the tight turn leading to the Booster and to accommodate a beam dump.

Located at the 100 meter point is a vertical access shaft sized to suit the 18 tonne magnet carrier. Handling of the shaft's pre-cast shielding beams, the magnet carrier and the beam line components will be by a mobile gantry crane.

2. Booster Complex

The Booster tunnel accommodates the A and B beam lines stacked with the A line over the B line. The tunnel structure is a cast-in-place concrete arch 5.9 meters wide by 4.8 meters high and approximately 214 meters in circumference.

Built within the center of the ring, but set back 8 meters to provide shielding, is the Booster building. This building has 3 stories below grade to accommodate equipment such as tunnel ventilation fans, magnet and rf power supplies. There are three stories above grade, the first accommodating the kicker cable drums, loading bay, offices, labs

and electrical switchgear. The second floor accommodates the computer room, offices and the KAON Factory control room. The third floor is predominantly offices with service space for the building mechanical system.

The below grade portion of the Booster complex is of concrete construction built in an open cut excavation. The above grade portion consists of a structural steel frame with the outer walls being a combination of precast concrete panels and metal cladding.

3. BC Transfer Line Tunnel

The BC Transfer Line is the beam line connecting the Booster with Main Ring.

The tunnel for this beam line is a rectangular cast-in-place concrete box section 3.8 meters wide, 3.2 meters high, approximately 105 meters long and accommodating an elevation change of 5.5 meters from the Booster complex up to the main ring tunnel. The tunnel is built in an open cut excavation which ranges in depth from 10 to 12 meters and is backfilled with a minimum cover of 8 meters or to the original grade, whichever is the greater, to provide shielding.

Access from the surface to the tunnel level is via a vertical access shaft similar to that located over the IA transfer line.

4. Main Ring

The Main Ring tunnel accommodates the C, D and E beam lines with C stacked over D on the inside of the race track and E separated horizontally by a minimum of 3.5 meters and a maximum of 4.088 meters. To allow reusable forms to be employed throughout the length of the main ring, the latter dimension was used in establishing a common width. The length of the Main Ring beam lines is 1076 meters with approximately 900 meters contained within the tunnel structure and the remainder within the Extraction Hall.

Various combinations of open-cut and driven tunnel were considered for the Main Ring, IA and BC transfer lines and Booster tunnel.

- Tunnel boring machine
- Top heading and bench
- Cut and cover excavation with
  - Concrete box
  - Cast-in-place concrete arch
  - Pre-cast concrete arch
  - Corrugated plate culvert

Cut and cover excavation with a cast-in-place concrete arch offered the best solution. It was considered the least expensive, offered the simplest form of construction, it could be built by many contractors and it allowed for changes in detail such as the provision of access tunnels for both personnel and services.

The tunnel size selected is 7.1 meters in width by 5.4 meters high. The open-cut excavation ranges in depth from 9 meters to 19 meters and employes 60° side slopes with an ejector dewatering system to handle ground water. It has been assumed that localized shotcrete shoring will also be required.

The tunnel will be backfilled with a minimum cover of 8 meters or to the original grade, whichever is the greater, to provide shielding.

Located around the Main Ring are six service buildings which house the tunnel ventilation and water cooling systems, magnet, kicker and rf power supplies, kicker cable drums and electrical switchgear.

These buildings are set back from the Main Ring tunnel by 8 meters for shielding reasons but are connected to the Main Ring by passageways which provide both personnel and service access.

Each building consists of a four storey below grade cast-in-place concrete structure with a seven meter high structural steel metal clad surface building. The roof of the surface building extends to cover the adjoining capacitor farms. A fenced-in yard is also provided at each service building for the transformers.

Also located around the ring are four buildings, primarily high roof steel structures providing cover for capacitors. A concrete shaft is provided at each location for cable access to the tunnel.

Large equipment access to the Main Ring tunnel is provided either through the Extraction Hall or via an access shaft not unlike those over the IA and BC tunnels. The main difference in this case is that rather than utilizing a mobile gantry crane, a 30 tonne bridge crane housed in a metal building is provided over the access shaft.

5. Extraction Hall

The Extraction Hall accommodates the C, D and E beam lines, slow and fast extraction lines and the switchyard wherein the extracted lines are divided into the primary experimental beam lines.

The various beam lines are housed in a 200 meter long cast-in-place concrete canyon, the floor of which is at the same elevation as that of the Main Ring tunnel floor.

Access to the full length and width of the canyon is provided by 5 meters of removable precast concrete beams. A 0 tonne overhead crane is utilized for handling of the precast beams, the magnet carrier and beam line components.

A metal clad structural steel surface building 200 meters long by 23 meters wide is located above the canyon with an adjoining annex building housing electrical switchgear and water cooling systems. Beyond the Extraction Hall is a cast-in-place tunnel structure 70 meters long housing the beam lines leading to the Experimental Hall.

6. Experimental Hall

The experimental areas are housed in a hall measuring 192 meters long by 74 meters wide with a height of 23 meters

from floor to underside of roof trusses and with a 40 meter by 30 meter extension housing the 6 GeV experimental facility. Both of these facilities provide open spaces free from structural framing elements with two 50 tonne bridge cranes in the Main Hall and 30 tonne bridge crane in the 6 GeV hall.

All below grade structures are cast-in-place concrete with above grade portions being structural steel with metal cladding.

Equipment access to the Experimental Hall floor is provided by four 5000 kilogram capacity elevators with platform sizes of 3 meters by 4 meters, a floor level truck access and an above floor loading dock located at the diagonally opposite end from which equipment can be lowered to the floor using one of the overhead cranes.

Equipment and personnel galleries are provided around the entire perimeter of the facility outboard of the crane coverage area.

7. Electrical Service

The KAON Factory electrical load would be approximately 80 megawatts. The recommended method of electrical power supply is by means of a dedicated 60 kVA circuit from B.C. Hydro's Camosun Station which is located approximately 2.5 kilometers east of the KAON site. This would require double circuiting of the existing TRIUMF overhead 60 kV transmission line located on a right of way through Pacific Spirit Park.

The receiving sub station located on the site would be an outdoor 60 kV installation with two 80/107 MVA transformers supplying primary standby transformation to the site distribution system.

The site electrical power distribution would be via an underground 25 kV system. Site electric load centres will have outdoor oil-filled transformers stepping the 25 kV distribution voltage down to utilization voltages of 4160 volts and 480 volts.

Subject to approval from UBC, maintenance standby power would be provided from the existing 60 kV circuit. Emergency standby power for critical and essential loads would be supplied from uninterrupted power supplies and diesel generation.

8. Mechanical Services

The mechanical services included in the conventional facilities consist of:

- low conductivity water cooling systems
- raw water cooling systems
- tunnel, service building and booster complex ventilation, air conditioning and plumbing systems
- electrical equipment ventilation and air conditioning systems
- mechanical control systems
- fire protection systems
- low level liquid waste systems
- site services (including sewers, storm drains, water lines and gas mains).

The low conductivity water systems consist of three systems:

- low active systems to cool all primary beam line components within shielded areas
- non-active systems to cool power supplies and other similar equipment outside of the shielded areas
- high active systems to cool targets, beam dumps and associated equipment

The raw water cooling system which provides cooling water to the LCW systems is designed to dissipate 100 megawatts of energy utilizing conventional forced air cooling towers. There are two raw water cooling systems, one ten megawatt system servicing the Booster complex and one 90 megawatt system servicing the Main Ring and initial and future experimental areas. The latter system will be phased in as the KAON Factory develops.

The tunnel ventilation system is based on the assumption that 97% of the energy is removed through the cooling towers via the LCW system with the remaining 3% being removed via ventilation systems and on the assumption that the maximum allowable tunnel temperature is 30°C. Cooling would be provided by mechanically cooled air conditioning systems located in the Booster complex and in each of the six Main Ring service buildings. Air capacity of these systems would be approximately 23,600 litres per second each. Air would be distributed along the length of the tunnel utilizing a plenum created at the top of the tunnel structure. All air associated with these systems would be recirculated while the beam is on. Provision has been made to achieve negative air pressure within the tunnel.

A direct digital control system would be provided for the monitoring and control of the mechanical system components. Separate monitoring and control stations would be provided in each of the six service buildings, one in the Booster complex and one for the experimental areas. A separate, remote, monitoring only station is to be provided in the Main KAON Factory control room in the Booster complex.

A pre-action fire sprinkler system would be utilized in all tunnels and all major buildings.

All floor drains, under-slab and perimeter drainage systems associated with the tunnels, Booster, service, extraction and experimental buildings would be directed to monitoring sumps prior to discharge to on-site site storm or sanitary sewers.

Chapter 8

BUILDING AND COMMISSIONING COST ESTIMATES AND SCHEDULES

PURPOSE

This section summarizes cost estimates for the construction phase based on conventional and technical engineering design work reported in earlier chapters. This chapter also discusses the process of building and commissioning the complete machine and presents cost estimates for the running in or operating phase.

CONSTRUCTION PHASE

Overall Construction Schedule

The schedule for construction of the KAON Factory is shown in Figure 8-1 and has been developed to provide coordination of technical and conventional construction with the objective of accelerating the beam through all five rings and reaching the design target of 30 GeV at the end of the capital program.

The overall period for the capital construction program was determined to be five years as shown in Figure 8-1. The five year program is planned to start formally in January 1991 on the assumption that several very key steps have been completed in the period following submission of this design report.

Issues at Startup

The schedule assumes that approval in principle to fund the KAON Factory is granted in mid 1990 with initial funding in place in October 1990. The schedule also assumes that the senior management and staff for KAON construction, including the Project Leader, would be put in place very shortly after approval in principle has been secured. This is viewed as a very important step as several matters must be attended to in a timely fashion, otherwise the five year program will be placed in jeopardy. Some of these key matters include:

- Establishment of the organizational structure for design and construction
- Establishment of hiring policies and hiring key technical staff
- Implementation of the process for further refining the initial experimental program to set the conventional and technical requirements of the experimental facilities by mid 1991.
- Establishment of office facilities for design staff.

These funding and staffing issues are two of the three raised by the international panel which evaluated the technical design (Chapter 3). We note here the needed balance between the pressures of building KAON and the pressure to use the facility.

Technical and Conventional Construction

Design, construction and installation periods for the technical components used in the scheduling are based on experiences of accelerator personnel at TRIUMF as well as those at other laboratories, together with vendor input. Separate detailed PERT charts have been established for each of the major technical component groups, i.e. magnets, power supplies, vacuum system, etc. The schedule assumes sequential commissioning of the two accelerators (see below). Achievement of 3 GeV in the Booster is scheduled for early 1995 with 30 GeV in the main rings following at the end of that year.

Design work on the conventional facilities is planned to start in early 1991. This is based on the assumption that the technical design would have advanced to the point that the precision of space, mechanical and electrical requirements of the accelerator would permit the most effective utilization of the conventional design consultants. The schedule also assumes that the conventional construction will be tendered in at least eight packages.

Cost estimate for construction

The KAON Factory capital cost estimate information presented in Table 8-1 is the result of the research, engineering and design, management and estimating procedures of the KAON Factory PDS team.

The capital cost estimate is presented in fiscal year 1989 Canadian dollars. The estimate is presented using the terms developed for discussion of the results of technical and conventional design components of this study (Chapters 3 and 7 respectively). The estimate is based on the following set of conditions or assumptions:

1. Construction of the KAON Factory would be adjacent and connected to the existing TRIUMF Meson facility and property.
2. Cost estimate does not include land acquisition costs, or

relocation costs for external groups currently operating on those lands (assumed to be a provincial responsibility and not to affect the total cost substantially).

3. Research and Development is not included in capital costs.
4. Replacements for components of finite lifetime are normally part of operating costs and are not included in capital costs.
5. Operating costs for the existing TRIUMF Meson facility or the KAON Factory are not included in the capital cost estimate.
6. Labour for building the KAON Factory would be supplied by both TRIUMF and private independent firms.

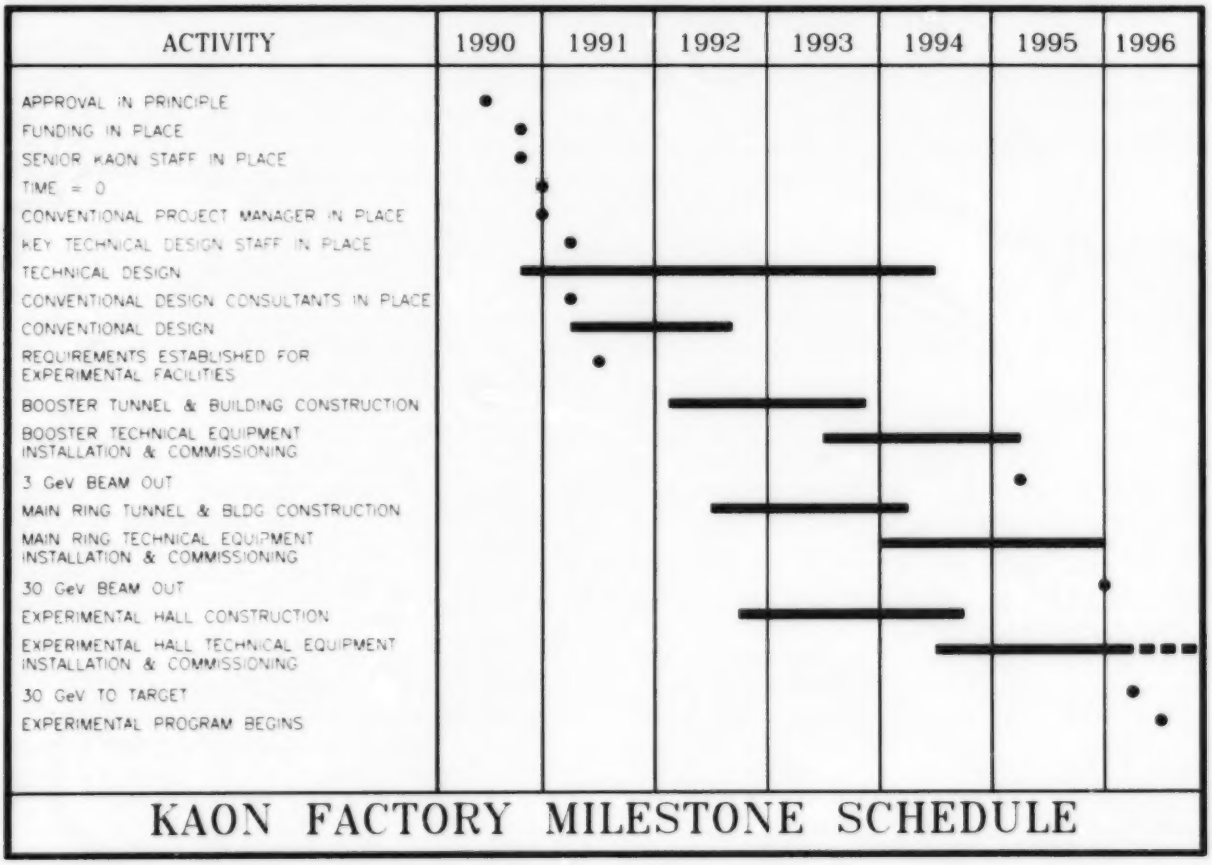

Figure 8-1 Construction Schedule

Table 8-1
Five year Capital Program Cost Estimate
[$Millions (1989)]

Technical Components		
Power Supplies	74.9	
Magnets	82.4	
Radiofrequency Systems	31.8	
Vacuum Systems	41.3	
Targets and Beam Dumps	1.0	
Shielding	31.1	
Remote Handling	10.1	
Safety & Security	3.0	
Beam Diagnostics	15.0	
Central Controls	24.4	
Kickers and Choppers	14.0	
Separators and Electric Septa	8.6	
Alignment and Survey	6.5	
SUBTOTAL	344.1	
Contingency on Magnets and Power Supplies (15%)	23.6	
Contingency on Other Technical (20%)	37.5	
TOTAL TECHNICAL		405.2
Conventional Facilities		
Tunnels and Underground Structures	23.9	
Mechanical Systems	27.8	
Electrical Systems	36.3	
Extraction Hall and Experimental Facilities	39.0	
Site Development and Support Buildings	24.0	
Other Services, e.g. telephone	2.0	
Temporary Project Services	14.2	
Project Management	7.5	
Conventional Engineering	10.1	
SUBTOTAL	184.8	
Contingency (10%)	18.5	
TOTAL CONVENTIONAL		203.3
TRIUMF/KAON Labour & Expenses		
Installation Manpower	26.8	
Management & Administration	6.9	
Design and Engineering	48.9	
Design Expenses	2.3	
SUBTOTAL TRIUMF/KAON LABOUR AND EXPENSES		84.9
PROJECT TOTAL		693.4

For comparison, the capital program cost estimate developed in 1987 was $571M in 1987 dollars. When adjusted to 1989 dollars using general prices indices, this is $621M. The estimate presented here represents an increase of only 11.5%, even though the machine specification and costing has been refined substantially.

Capital Program Cash Flow

Annual cash flow requirements for the five year capital program are presented in Table 8-2, using a three part breakdown; design and construction, contingency and escalation.

Escalation rates applied to the project were developed from information obtained from the Conference Board of Canada, British Columbia Ministry of Finance and Corporate Relations and review with independent private financial resources. The escalation rates and their scaling factors used for the cash flow estimates are:

Fiscal year	Escalation %	Scaling Factor
1989	0.0	1.000
1990	4.5	1.045
1991	7.0*	1.120
1992	4.7	1.170
1993	4.7	1.230
1994	5.0	1.290
1995	5.0	1.350
1996	5.0	1.420

***Note:** 1991 escalation factor of 7% has taken into account the possible effect of the proposed Goods and Services Tax.

Table 8-2 Five Year Capital Program Cash Flow
[$Millions]

Item	Year 1	Year 2	Year 3	Year 4	Year 5	TOTAL
Design and Construction	42.6	103.4	161.6	164.4	142.4	614.5
Contingency	5.4	13.2	20.8	21.1	18.4	79.0
Subtotal	48.0	116.7	182.4	185.5	160.8	693.4
Escalation	5.8	19.8	41.9	53.8	56.3	177.6
TOTAL	53.8	136.5	224.3	239.3	217.1	871.1

The international accelerator review panel raised the possibility of a six year construction schedule. The cost estimate and construction schedule are, however, predicated on the five year period as chosen by the Steering Committee. For information, Table 8-3 presents a cash flow for a six year capital program. The escalation factors are as described above.

Table 8-3 Six Year Capital Program Cash Flow
[$Millions]

ITEM	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	TOTAL
Design and Construction	36.6	88.4	143.6	139.4	140.4	81.0	629.5
Contingency	4.6	11.1	18.4	17.1	17.6	10.3	79.0
Subtotal	41.1	99.5	162.0	156.5	158.1	91.3	708.5
Escalation	4.9	16.9	37.3	45.4	55.3	38.3	198.1
TOTAL	46.1	116.4	199.2	201.9	213.3	129.6	906.6

COMMISSIONING THE KAON FACTORY ACCELERATOR COMPLEX

Since building, commissioning and operating the KAON Factory would not be a conventional project, this section provides an overview of the complete process from the perspective of the machine and the stages of its development.

The construction schedule (Figure 8-1) has a set of milestones for the completion of its various activities. These have a time sequence parallel to that of the protons in the machine, as they undergo acceleration from the TRIUMF cyclotron to the Extender Ring. Namely the modification of the TRIUMF Cyclotron to operate as the Injector would be completed first, then the Booster complex, and finally the Main Rings and the Driver synchrotron. This sequence lends itself to a staged program of commissioning which can go on in parallel with the building of the later components in the chain.

Extraction from TRIUMF

Two years after the start of the project, the H^- extraction system of the TRIUMF cyclotron should be ready for commissioning. During these two years the Cyclotron could operate for the 500 MeV physics program with a largely uninterrupted schedule. Increasingly during the third year the tests of the extraction would impinge on this program. It is difficult to envisage any time for physics in the fourth and fifth years.

The H^- ions would be transported out of the cyclotron vault through the first few elements of the IA transfer line which is designed to transport beam from the cyclotron Injector to the Accumulator ring. The intensity would be deliberately kept at a low level (about 1 microampere) so as to reduce activation of components and facilitate the provision of beam dumps. It does mean, however, that the diagnostic devices used to measure the energy spread, spatial distribution and angular divergence of the extracted beam must be able to operate effectively at approximately 1% of the design current. These beam parameters should become available as soon as possible in order to understand what is required to tailor the beam for injection into the Accumulator ring. This timescale also sets a target date by which the first parts of the KAON Factory controls system must become operational.

The IA Transfer line is shown due for completion at the end of the third year. The provision of a temporary 1 microampere beam dump near the entrance into the Accumulator ring would permit the setting up of IA components, and more importantly a remeasuring of the beam properties at injection into the Accumulator Ring.

Booster Commissioning

The Accumulator Ring is planned to be ready for beam in the summer of the fourth year of construction (July 1994) and the Booster would follow by the fall of the same year (October 1994). At this point the whole Booster complex should be ready for commissioning. Initially the Booster magnets would be set for the injection energy of the A-ring, and the Booster merely used as a transport system to take the beam to a dump while the injection scheme into A is studied. Eventually the Booster Synchrotron would be brought into operation as a 3 GeV 50 Hz machine. The time window for these operations is set for approximately one year, since by the fall of the fifth year (October 1995), the final ring of the main complex, the Extender, should be ready to receive beam.

The running in of the Booster complex is a very significant piece of accelerator physics. It would demand expertise from all of the technical groups in the KAON Project with the possible exception of the experimental facilities group and it is envisaged that a dedicated team is "left behind" to get the Booster working, while the rest of the KAON Project members complete construction of the Main Rings. The work with the Booster would be at low current, about 1 microampere, again making demands on the dynamic range of the sensitivity of the diagnostic elements and again requiring full utilization of the final controls system.

Driver Commissioning

The commissioning of the Driver synchrotron should commence in the fall of the fifth year (October 1995); by that time the Booster should be operating reliably as a 3 GeV injector into the Collector ring. The completion of the project is nominally signified by the extraction of a 30 GeV beam from the Extender ring in the spring of the sixth year. This is an enormously ambitious, but nonetheless realizable, timescale. The Driver (30 Gev, 10 Hz) is a somewhat simpler machine than the Booster, although the time allotted to bring it into initial operation is only six months.

In order to achieve this commissioning, in parallel with continued construction, a significant operation schedule must take place during the building phase. The TRIUMF Cyclotron would have to operate essentially as a fulltime injector from the beginning of the fourth year. The Cyclotron and Booster complex would be in operation by the fall of year four, and the full KAON Accelerator complex would commence operation around the middle of year five and continue on demand until a steady state of operation for the initial physics program can be put in place in the sixth year of the project.

At this point the KAON Factory should be operational at 30 GeV with a slow extracted beam from the Extender a little in excess of 1 microampere. The reliability should be sufficiently good to support the initial physics program. It is anticipated that over a period of approximately two years the beam current will be raised to the design level of 100 microamperes. This process would require the commissioning of new control elements for the beam, and the addition of collimators and scrapers to keep induced activity from beam losses to a minimum, otherwise the machine would quickly become unserviceable. The fast extraction from the Driver will be brought into operation, thus enabling the neutrino experimental program. This "running-in" of the machine will alternate with periods of steady delivery of beam for physics at increasing beam currents. It is a procedure which should not be hurried, since undoubtedly the most challenging aspect of the full commissioning of the KAON Factory will be the demonstration of controlled operation with 3 megawatts of beam power (i.e. 30 GeV at 100 microamperes).

MANAGEMENT AND ORGANIZATION

Introduction

After approval, the organization of TRIUMF would have to accommodate two distinct situations associated with the KAON Factory. There would be the building and commissioning phase, which would be followed by the operating and "running in" phase. The organizational structure should be set up so that the transition between these phases is as smooth as possible, and there is very little disruption to lines of responsibility. Prior to approval there would be a period during which TRIUMF will have to strengthen its groups, by acquiring targeted experts. This would not be an easy process, without the full approval for construction, but negotiations at some level must take place, otherwise there would be a significant delay while the appropriate team is assembled after the full approval.

Building and Commissioning Phase

During the Building and Commissioning of KAON the TRIUMF organization would have to set up an internal management structure which performs the following functions:

1. builds KAON in the most efficient and technically sound manner possible,
2. initially runs the 500 MeV program of the TRIUMF Cyclotron for Intermediate Energy Physics; after approximately 2 years this program would gradually be run down, as the cyclotron is more and more in demand as an injector for KAON, supplying H^- ions for injection into the Accumulator ring at 450 MeV, and
3. defines and selects the science program of the KAON Factory; this would involve considerable interaction with the International Community of sub-atomic physicists as

experiments and collaborations emerge, and eventually would lead to significant construction of apparatus for the Canadian content of the science program.

The proposed structure for the Building and Commissioning phase is shown in Fig. 8-2 where the KAON Factory appears as a self-contained project inside TRIUMF, depending on the host laboratory only for H^- extraction and science input. The KAON Factory Project would contain a commercial Project Management team, through which it would link to the firms responsible for the various items of Conventional Construction.

This scheme is demanding of the senior management, but it permits the appointment of an experienced accelerator builder of international repute to head the KAON Factory during the construction phase. This is believed to be essential to ensure success in this complex project. If possible, this person should be identified early and brought on board on leave from his or her present position or in a part-time fashion before the final formal approval for construction.

The Director of TRIUMF should have the responsibility to represent the laboratory to Government agencies, both the 500 MeV program and the KAON Project; however, the financial responsibility must remain clearly defined. The KAON Director should be responsible for the Project budget, and those costs identified as KAON Operation, during the building phase. The TRIUMF Director should be responsible for the funds allocated to TRIUMF Operation, and the build-up of the KAON Experimental Program.

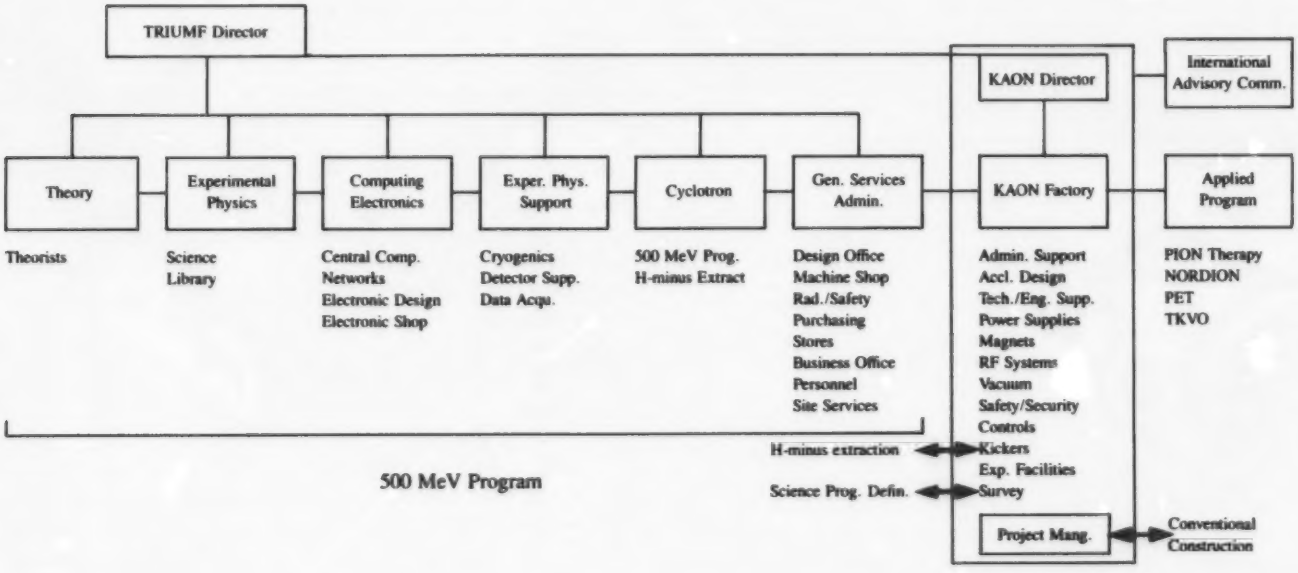

Fig. 8-2 KAON Factory Building Phase

An International Advisory Committee should be established. Its membership should reflect the external contributions to KAON and Canadian experts should be added to provide a balance. The expertise of the members should most likely be changed during the history of the project, initially emphasis should be given to accelerator experts, later the emphasis would shift towards the overall science of the laboratory. Alternatively, there might be, from the beginning, two separate international committees, one on accelerators and the other on KAON science.

No specific structure is shown for the KAON Project during the building phase; it would clearly be defined by the leader. However, it is known that the project would involve 500 people, and there will be a need for very strong technical groups, e.g., Accelerator Design, Power Supplies, Magnets, RF Systems, Vacuum, Kicker Magnets, Experimental Facilities, Controls and Survey. It is also envisaged that there would be a need for two or three senior staff to assist the Project Director, for example, a subdivision of responsibilities into the Booster and its rings, and the Driver and its rings, is an obvious one, which would carry over into the commissioning of the machines. In addition, the project leader must receive strong support from project management services provided by an outside contractor. It is also important to note that no governance structure is shown. It is assumed this would be established as appropriate by funding agencies and the TRIUMF Board of Management.

Operating Phase

At the end of the construction period, TRIUMF should convert to a management scheme as shown in Fig. 8-3. The KAON Project becomes the Synchrotron Division, the Cyclotron Division disappears, becoming the Injector Group, and the Experimental Physics Support Group is boosted by the additional responsibility for Experimental Facilities. The main reorganization takes place among the Administrative and Technical Support Groups, these now become the responsibility of the General Services and Administration Division. This process allows for a conscious choice in the final size of the laboratory, since some of the people within the KAON Project could be hired for the construction phase only.

The TRIUMF/KAON Director now assumes the full financial responsibility for the operation of the KAON Factory. The crucial appointment would be that of Head of the Synchrotron Division, since there will remain 2 or 3 years of rather intense machine development as the current is raised to the design level of 100 microamperes. This would be a iifficult task technically, demanding considerable synchrotron expertise; it should be the overall top priority of the TRIUMF/KAON Laboratory.

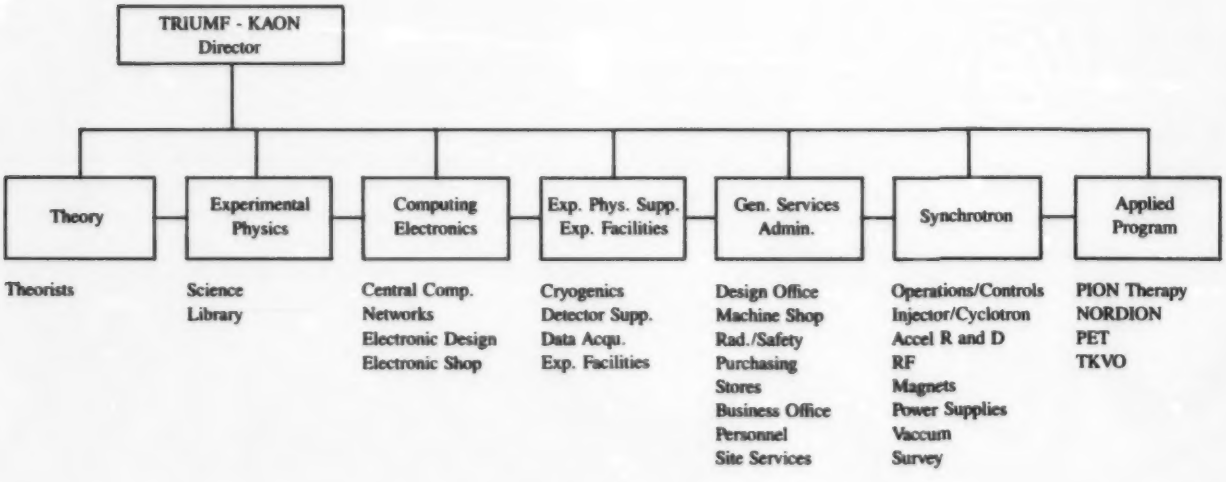

Fig. 8-3 KAON Factory Operating Phase

OPERATING COST ESTIMATES

TRIUMF Operations

The current operating budget for TRIUMF provides the starting point for considering operating costs during the building and commissioning period. The previous section has described the operational tasks to be performed as the machine is commissioned and the need for operating budgets to ramp up. The two major TRIUMF budget areas (research and development and cyclotron operations) would carry forward and then phase out as the project completes the building and commissioning phase. Two new major budget areas to be introduced for KAON are experimental infrastructure and the phasing in of KAON operations. The Building and Commissioning section of Table 8-4 shows the estimated operating budget requirements for the building and commissioning phase.

The total operating cost over the five year period (mostly in years 4 and 5) would be $210 million, or an aggregate increase of about $85 million over TRIUMF expenditures with no other increases.

The operating budget would achieve a relatively steady level as the organization takes on its long term form with full integration of KAON operations. The ongoing requirement for experimental infrastructure reflects the experience of TRIUMF and other major laboratories around the world for continuing development of the machine and research facilities. The Operating and "Running-in" Phase section of Table 8-4 shows typical operating budget for the post construction period, starting in year 6.

Table 8-4 Operating Cost Estimate
[$ Millions (1989)]

PHASE	Building & Commissioning					Running	
Project Year	1	2	3	4	5	6	7
Budget Category							
Research & Development	7	7	6	4	4	-	-
Cyclotron Operations	20	20	17	13	10	-	-
(sub total TRIUMF Operations)	27	27	23	17	14	-	-
KAON Operations	-	-	7	25	43	71	71
Experimental Infrastructure	-	2	5	10	10	19	19
TRIUMF-KAON TOTAL	27	29	35	52	67	90	90

Support for Canadian Researchers at TRIUMF-KAON

University based researchers across Canada require support through research grants to perform their experiments at TRIUMF. The level of support is determined by the success of their proposed research in open competition under a peer review process. At present, this amounts to about $3.5 million annually from NSERC. It is anticipated that Canadian researchers would comprise about one-third of the total user community for KAON and would require additional funding to prepare and run experiments. While exact levels will depend on the excellence of the Canadian proposals, it is expected that levels would increase to about $8 million.

Table 8-5 Summary of Overall Operating Costs
[$ Millions (1989)]

PHASE	Building & Commissioning					Running	
Project Year Budget Category	1	2	3	4	5	6	7
TRIUMF Operations	27	27	23	17	14	-	-
KAON Operations	-	-	7	25	43	71	71
Experimental Infrastructure	-	2	5	10	10	19	19
TRIUMF/KAON TOTAL	27	29	35	52	67	90	90
Support to Researchers(NSERC)	5	8	8	8	8	8	8
TOTAL	32	37	43	60	75	98	98

SUMMARY

Table 8-5 shows the combined costs of operating TRIUMF-KAON and support Canadian university researchers. There is a gradual growth during the construction period, after which an ongoing level of $98 million is attained after the construction period.

COSTS OF DECOMMISSIONING KAON OR THE PRESENT TRIUMF

There appear to be no special problems with decommissioning the future KAON facility or the present TRIUMF and its cyclotron, which differ significantly from those problems associated with decommissioning any large civil structure. TRIUMF has neither the large inventory of fission products associated with a nuclear reactor, nor the toxic chemicals associated with many industrial activities. TRIUMF is on a university campus and most likely if the project terminates, its civil structures would remain and find some other end use. The removal of experimental facilities — such as the large cyclotron magnet — would result in most such components ending up in other laboratories with the new owners paying for removal. The small amount of radioactive material is mostly short-lived (maximum 5 years). Consequently, some concrete shielding blocks might be stored for a few years before becoming acceptable landfill. The total cost of removal of experimental facilities should be only a small fraction of TRIUMF's annual operating costs. If the end use requires removal of all buildings, then the cost of doing so would be a reasonable fraction of the initial construction cost. The same applies in respect to the KAON Factory.

Chapter 9

IMPLICATIONS OF THE KAON FACTORY

PURPOSE

This component of the study was aimed at reviewing issues in the legal, environmental and economic areas that could have implications on the proposed KAON Factory.

LEGAL ISSUES

Legal issues raised in respect of the KAON Factory proposal were addressed. The issues of real property, environmental issues, legal issues currently facing TRIUMF and KAON corporate/legal structure were considered.

The assessment concluded that, on the basis of the information available at the time of the examination, there does not appear to be any legal issue which would preclude the project from proceeding. Specific proposals and options would need to be addressed from a legal perspective as further information becomes available.

ENVIRONMENTAL ISSUES

Scope of the Study

The initial environmental assessment, consistent with Federal Environmental Assessment Review Office and Environmental Assessment Review Process requirements, was undertaken to evaluate environmental effects that could result from construction of the KAON Factory and to identify and review any potential risks as well, as mitigative measures that may be required. Accordingly, the scope of studies comprising the assessment was comprehensive, encompassing vegetation and wildlife of the project site and its vicinity, aesthetic and recreational values, land use and social features, groundwater and drainage, air quality, environmental noise, radiation effects (both ionizing and non-ionizing) and seismology.

Public Process

A public consultation program comprising two public meetings was carried out as an integral part of the environmental assessment. The first meeting was held early in the work program, and the second during the draft report preparation stage. These meetings included representatives from most of the important environmental groups. The public response received during the meetings revealed a wide range of concerns rather than any single issue. The most important public concerns related to discharges to the atmosphere, wildlife impacts, noise, changes to groundwater conditions and radiation. These and other concerns were addressed directly during the meetings by expert members of the assessment team and in various studies and investigations undertaken during the assessment. Judging from positive comments and general approbation received at the second hearing from members of the public concerning the conduct of the public consultation program and environmental assessment, it seems apparent that the program provided a satisfactory opportunity for public discussion of the environmental implications of the project. Those who registered their attendance at the two public consultation meetings will be notified by letter of the availability of this environmental assessment report, which is expected to be placed in select public libraries in due course.

Environmental Impacts

The environmental assessment has identified a range of environmental impacts that would result or potentially result from construction and operation of KAON. Most of the potential impacts are of minor consequence and involve little or no measurable environmental risk. Many of the impacts are only of consequence in terms of land-use and environmental modifications of the project site itself. To a large extent these impacts are unavoidable but alternatives for mitigating them have been considered and, in most cases, reasonable measures for mitigation identified. All residual impacts associated with vegetation and wildlife, aesthetics and recreational uses, land use and social features are considered manageable and none are considered to be of sufficient significance to require more detailed study or consideration prior to a decision being made on project approval.

The more significant potential impacts are as follows:

a). Under certain climatic conditions, water vapour emissions from cooling towers would create visible plumes, which under an assumed worst case scenario of climatic conditions, could create a visibility concern on Southwest Marine Drive. Although this impact would occur infrequently, further consideration of this effect is warranted.

b). On-site construction activities would generate significant temporary noise impacts on users of neighboring UBC facilities, TRIUMF staff and users of Pacific Spirit Regional Park. Disruption of blue heron nesting activity in Pacific Spirit Regional Park during the February to mid-August breeding season may also occur as a result of sudden, loud and unpredictable construction noises. These impacts could be mitigated to a significant extent by temporary berming, appropriate construction scheduling and proper attention to maintenance of construction equipment.

c). Operational noise from cooling towers and transformers would be clearly audible on the KAON site, along Southwest Marine Drive and at the boundary of Pacific Spirit

Regional Park. Measures for reducing cooling tower and transformer noise include design and equipment selection options, such as use of shielding walls and sound absorption materials.

d). Modification of site drainage due to installation of subsurface drains and to excavation, backfilling, berming and grading activities may alter soil moisture conditions in certain perimeter areas and thus have an impact on existing vegetation. Most notable of these potential impacts are alteration of soil moisture conditions in the vegetation corridor along Southwest Marine drive due to the effects of subsurface drainage associated with the west side of the racetrack and extraction hall, alteration of drainage and soil moisture conditions along the boundary of Pacific Spirit Regional Park due to parking lot construction. Careful drainage design in these perimeter areas would mitigate these impacts.

These potential impacts should be given further consideration and investigation during the detailed design stage of the project.

Other factors examined and their determination are as follows:

a). The potential for groundwater contamination by radionuclides and various chemical materials that may be utilized during operations is minimal. Careful on-site management of potential contaminant sources, along with the proposed subsurface seepage collection system and regular groundwater monitoring are important mitigation measures to ensure no significant groundwater contamination occurs. Changes in groundwater conditions resulting from construction of then project would not contribute to or exacerbate erosion and instability along the Point Grey Peninsula.

b). Based on a thorough review of radiation effects associated with KAON radioactivity and governing regulatory provisions, it is quite apparent that KAON, as is the case with the TRIUMF facility, would be designed and operated to maintain worker exposure to radiation well below regulatory limits. It is concluded that radiation doses resulting from KAON operations and potentially affecting the general public and the environment, would be very small compared to variations in natural background radiation, and would be well below Atomic Energy Control Board regulatory limits for radiation exposure. Radiation from KAON would not represent any risk to the public or the environment. It should be emphasized that other large accelerator facilities, for example HERA in Hamburg and LEP in Geneva are located in places at least as urban as TRIUMF.

c). With respect to electric and magnetic field effects of the B.C. Hydro power transmission line that would supply energy to KAON, this assessment concludes that there is no basis in present knowledge to anticipate any resultant biological or health effects along the right of way of either the existing or expanded transmission line through Pacific Spirit Regional Park.

d). A seismology assessment of the Lower Mainland and adjacent continental margin has identified the magnitude of the 475-year return period earthquake required for structural design to meet the National Building Code of Canada (NBCC). Representative 475-year earthquake events that are likely to affect the Lower Mainland have a magnitude of 6.5 to 7.0. Design of the KAON to NBCC requirements is considered appropriate, as conceivable project failures under conditions imposed by a maximum credible earthquake event affecting the Lower Mainland would not adversely impact the environment.

e). Reconsideration of the decision to reject underground installation of the existing electricity transmission line that crosses Pacific Spirit Regional Park and that would serve KAON is warranted. Although use of the existing line would not result in any significant negative environmental impacts, its placement underground would represent a significant environmental enhancement with respect to aesthetics and public use of Pacific Spirit Regional Park.

Finally, an environmental monitor should be retained during project construction to ensure that the project would be implemented to avoid or limit impacts identified in this assessment, and that proposed mitigation measures are fully considered.

ECONOMIC ASSESSMENT

Scope of the Study

The KAON impact study conducted two separate economic/strategic studies of the proposed KAON Factory which together constitute the overall economic evaluation of the project.

The first, entitled **The Canadian Industrial Capability Study** (Chapter 6) evaluated the capability of Canadian business to meet the industrial needs of building the KAON Factory. A survey of Canadian business instituted as part of the study would be a useful tool in maximizing the sourcing benefits of component technologies for the project. The second was entitled **KAON Economic Assessment.** The purpose of this study was to evaluate the economic costs and benefits of the project during construction and operations, as well as to evaluate the overall economic impact of the proposed project.

Study Results

The potential benefits of a research facility such as the proposed KAON Factory could be considerable. These benefits would arise both from the initial construction phase and from the research which would be performed at the completed facility. The KAON Factory construction would require extensive high technology components. Canadian industrial partic-

ipation in supplying KAON Factory requirements offers the potential for industry to enhance its technical prowess and international trading competitiveness and open new export markets.

During construction, the impact assessment indicates that the KAON project would generate up to $550 million of Gross Domestic Product, create up to 17,000 person years of employment and generate up to $1.1 billion in industrial activity. During operations, it is estimated that the project would generate over $77 million per year in industrial activity yielding up to $42 million in GDP and provide up to 1900 person years of employment. It must be stressed that these are gross measures which do not reflect the costs of creating the economic activity; they are, in fact, the benefit of spending money in a certain fashion rather than net benefits to the economy of the expenditure. In order to have a basis to compare the economic impact of the KAON project to other possible government expenditures, the consultants simulated a general government expenditure on an equivalent amount. They concluded that the case of employment, the multipliers generated by the KAON expenditure would be marginally higher than those generated by a general government expenditure. In terms of GDP, the multipliers obtained from such a general expenditure would have a marginally higher impact than would the expenditure for the KAON project.

The consultants undertook a benefit-cost analysis of the project. This analysis was not able to capture all elements of the output stream which are not quantified in the marketplace (including basic scientific research). In spite of certain computational difficulties relating to the quantification of the economic benefits of research, the consultants prepared a "benchmark" estimate of the overall project costs and benefits, which in their professional judgement gives a reasonable picture of the project's quantifiable economic impact. They concluded that their benchmark estimate indicates a residual $188 million deficit for the overall KAON project; this deficit would thus have to be justified by all the non-quantifiable economic, social, and scientific benefits of the project.

In summary, the studies have provided a useful framework for categorizing the costs and benefits of the KAON project. Costs proved more easy to quantify than benefits and, as such, the project is a difficult challenge for economic assessment. From the best available information, and recognizing that a full quantification of all benefits was not possible, the measured project benefits can still fully account for nearly 80 per cent of the project costs.

Chapter 10

CONCLUSION

The Steering Committee believes that the KAON Factory Project is feasible and can be successfully accomplished with the costs and schedule presented. There is a reasonable expectation that $200 million in international funding can be negotiated. International support for the science and the proposed experimental program is excellent. The Steering Committee is convinced that all the information needed to make the decision is available in this report and its accompanying technical reports. The Steering Committee is of the unanimous and strong opinion that the Canadian and international scientific community is ready and waiting for the KAON Factory to proceed. An early decision is clearly needed.